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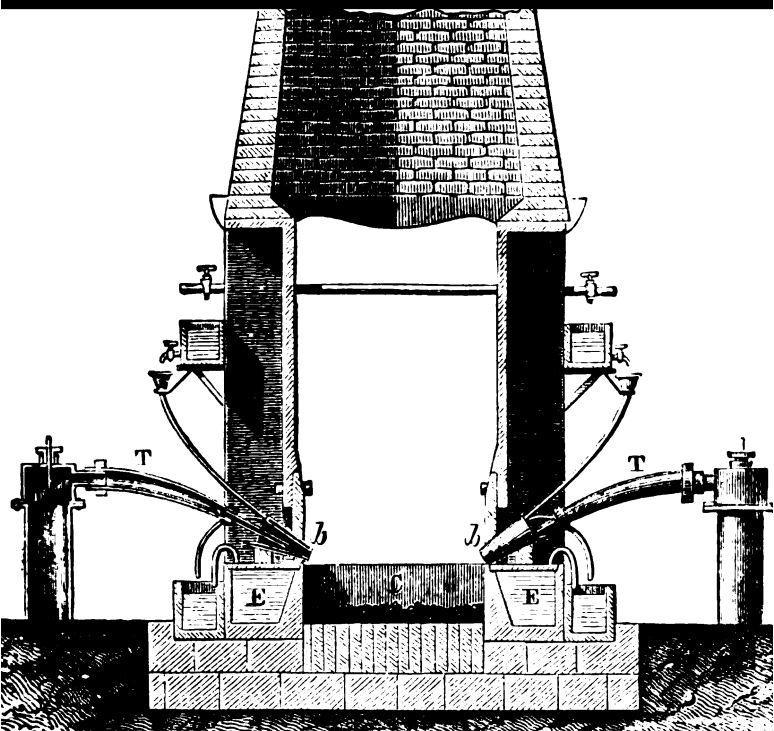
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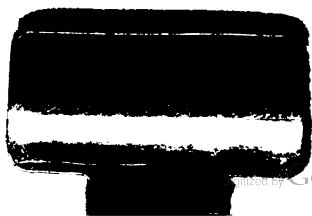
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*Elements of metallurgy,
by W.J. and W.J. Harrison*

William Jerome Harrison

1798. 2. 21.



ELEMENTS OF METALLURGY



BLACKIE'S SCIENCE TEXT-BOOKS

ELEMENTS
OF
METALLURGY

BY

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PREFACE.

This elementary text-book of Metallurgy has been written on the lines laid down in the syllabus for that subject as prescribed by the Government Department of Science and Art.¹

It is hoped that the work may prove of general utility to students, manufacturers, and workmen, and indeed to all who are interested in what must be considered as one of the most important of all the industrial arts carried on in this country.

It must be remembered, however, that this little book is to be regarded only as an introduction to the study of Metallurgy, and that works of reference (such as are named in the Appendix) must be consulted for many details, and for particulars of new or advanced processes.

Students who use this text-book in preparing for the South Kensington examinations are advised to study in connection with it the *Guide to the Examination in Elementary Metallurgy, with Answers to all the Questions* (Blackie & Son, price 6d.).

BIRMINGHAM, 1894.

W. JEROME HARRISON.

WILLIAM J. HARRISON, JR.

¹ See the *Directory for Science and Art Classes* (South Kensington), price Sixpence (published annually, in September), of any bookseller.

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ELEMENTARY METALLURGY.

SECTION I.

INTRODUCTORY SUBJECTS AND FUEL.

CHAPTER I.

INTRODUCTION—HISTORICAL NOTES—CHEMICAL PRELIMINARIES.

What is "Metallurgy"? Metallurgy is an art based upon the science of chemistry. Metals rarely occur pure, or free, or in the separate state. As a rule we find metals existing in the crust of the earth united with other substances to form what are known as *ores*. Now metallurgy is the art of extracting metals from these ores, thus obtaining them in the pure or uncombined condition.

But metallurgy does more than this. It teaches us not only how to extract metals from their ores most cheaply and most conveniently; but also how to treat or prepare them, so that they shall be of most service for the various uses to which they are commercially applied.

A knowledge of chemistry is indispensable to the metallurgist who would work otherwise than by "rule of thumb". Now chemistry (as a science) practically only came into existence during the present century. Hence, such history as metallurgy has prior to the year 1800, merely presents us with a view of workers of two classes:—

(a) Men who, by a series of fortunate "accidents", had learned—the knowledge being stored up, and trans-

mitted from generation to generation—to smelt the ores of copper, iron, &c.; and painfully, and at the expense of considerable labour, to extract the metals therefrom; and—

(b) Men—known as the *alchemists*—who during the Middle Ages theorized upon their insufficient knowledge of chemistry, and who attempted to transmute or change the “base” metals (as lead, &c.) into the “noble” or precious metals known as gold and silver.

Sciences which render aid to Metallurgy. Chemistry is the science upon which the art of metallurgy is based; and it is impossible to become an expert metallurgist without an adequate knowledge of chemistry. But although a *general* knowledge of chemistry is necessary, yet the field now covered by this science is so large that the metallurgist will find it necessary to confine his special attention to that section of it which refers to the useful metals.

In the *discovery* of metallic ores the sciences of Geology and Mineralogy render great and indispensable aid. They teach us how to recognize the various minerals, and how to search for them in any district or tract of country.

For the most convenient and economical methods of extraction of ores from the earth we must look to Mining as our guide: while Mechanics will teach us how to construct and to erect the various machines, furnaces, &c., which are indispensable in metallurgical operations.

The Ages of Stone, of Bronze, and of Iron. It appears certain that there was a time when metals—as such—were altogether unknown; and when men fashioned such tools as they needed out of stone, bone, and wood. Buried in the surface deposits—the gravel-beds, peat-bogs, and surface soil—of nearly all countries we find the relics of this Stone Age in the shape of axe-heads, knives, arrow-heads, &c., made of flint and of other hard stones.

The first *metal* to be discovered was apparently *copper*; but it was soon found that the addition of a little *tin* to

the copper much improved it for most purposes; and hence we find the Stone Age succeeded by a Bronze Age. Lastly, the art of smelting the ores of iron was discovered; and for general use that metal has never been supplanted by any other, so that we are still living in the Iron Age.

As to the *date* of the discovery of metals, nothing certain has been discovered; but it is conjectured that the Bronze Age began in Great Britain about 10,000 years ago.

What is a Metal?

1. *Metals are opaque substances.* That is, metals are the very opposite of such non-metallic substances as rock-crystal, the diamond, &c., which readily transmit the rays of light, and are therefore called *transparent*. Silver and gold can, however, be rolled out into layers so thin, that light is able to pass through them. If a piece of gold-leaf be placed between two glass plates (so that it can be conveniently handled), it will be found to transmit the *green* rays of light.

2. *Metals are lustrous.* They have a peculiar bright or shining appearance, owing to their power of reflecting light. Several non-metals—as the diamond, &c.—are also lustrous; but they have not the true “metallic lustre”.

3. *Metals are good conductors of heat.* Place a rod of any metal side by side with a rod of the same size of any non-metal, so that their two lower ends dip into hot water contained in a vessel. In a few minutes the end of the metal rod which is out of the water will be found to be quite warm (showing that the heat has travelled from end to end of the rod), while the outer end of the non-metal remains quite cool.

4. *Metals are good conductors of electricity.* Telegraph wires are invariably made of metal (iron or copper). If even a foot of the metal wire be removed, and a piece of some dry non-metal (as sulphur, carbon, &c.) be substituted for it, it will be found that no message can be transmitted, for the electricity cannot pass along the non-metal.

5. At ordinary temperatures all metals exist in the *solid* state, with the one exception of mercury.

6. The metals are, as a rule, *much denser, and therefore much heavier*, than the non-metals. There are three metals, however—lithium, sodium, and potassium—which are *lighter* than water; and which therefore float upon that liquid.

7. Nearly all the metals are very *malleable* and *ductile*.

8. The metals are *electro-positive*, as compared with the non-metals, which are electro-negative.

9. The metals combine with oxygen, and with hydrogen and oxygen, to form certain chemical compounds which are known as *bases*.

Non-metals, on the contrary, unite with the same elements (O and H) to form *acids*.

Metals here treated of. In the Elementary stage of Metallurgy, the attention of the student is restricted to the following nine metals (considering iron as distinct from steel):—

{ Iron	{ Copper
{ Steel	{ Zinc
{ Gold	{ Lead
{ Silver	{ Tin
	{ Mercury

These metals fall naturally into three groups or sections (as shown by the brackets). But it is necessary to also add an introductory section, in which the general properties of metals are considered; and which includes, also, a description of the Fuel used in nearly all metallurgical operations.

The Chemical Elements.—Considered from a chemical point of view, an element is a *simple substance*. It is a kind of matter which cannot be decomposed. Of these simple substances or elements about seventy are now known. Fifty-five of the elements are metals; and fifteen are non-metals.

COMPLETE TABLE OF THE SYMBOLS, &c., OF THE ELEMENTS.

THE FIVE GASEOUS ELEMENTS.

Name.		Symbol.	Atomic Weight.
Chlorine.....	All Non-metals,	..... Cl	35½
Fluorine .....		..... F	19
Hydrogen .....		..... H	1
Nitrogen.....		..... N	14
Oxygen.....		..... O	16

THE TWO LIQUID ELEMENTS.

Name.		Symbol.	Atomic Weight.
Bromine (A Non-metal).....		Br	80
Mercury ¹ { or Quicksilver, } a Metal, }		Hg	200

THE NINE SOLID NON-METALLIC ELEMENTS.

Name.	Symbol.	Atomic Weight.
Arsenic ²	As	75
Boron	B	11
Carbon	C	12
Iodine	I	127
Phosphorus	P	31
Selenium	Se	79
Silicon	Si	28
Sulphur	S	32
Tellurium	Te	125

TWENTY-TWO COMMON METALLIC ELEMENTS

(ALL SOLIDS).

Name.	Symbol.	Atomic Weight.
Aluminium	Al	27
Antimony (Stibium)	Sb	120
Barium	Ba	137
Bismuth	Bi	208
Cadmium	Cd	112
Calcium	Ca	40

¹ The Latin name for Mercury is *Hydrargyrum*; whence its symbol Hg.

² Arsenic may be considered as forming a link between the metals and the non-metals. In its physical properties it resembles the former, and in its chemical properties the latter. In Metallurgy arsenic is generally considered as a *metal*.

Name.	Symbol.	Atomic Weight.
Chromium	Cr	52
Cobalt	Co	59
Copper (Cuprum)	Cu	63
Gold (Aurum)	Au	196
Iron (Ferrum)	Fe	56
Lead (Plumbum)	Pb	206½
Magnesium	Mg	24
Manganese	Mn	55
Nickel	Ni	58½
Platinum	Pt	194
Potassium (Kalium)	K	39
Silver (Argentum)	Ag	108
Sodium (Natrium)	Na	23
Strontium	Sr	87
Tin (Stannum)	Sn	118
Zinc	Zn	65

THE THIRTY-TWO RARE METALLIC ELEMENTS

(ALL SOLIDS).

Name.	Symbol.	Atomic Weight.
Beryllium	Be	9
Cæsium	Cs	133
Cerium	Ce	141
Decipium	Dp	159
Didymium	Di	144
Erbium	Er	166
Gallium	Ga	69
Germanium	Ge	72
Indium	In	113
Iridium	Ir	192½
Lanthanum	La	138½
Lithium	Li	7
Molybdenum	Mo	96
Niobium	Nb	94
Norwegium	Ng	214
Osmium	Os	199
Palladium	Pd	106
Rhodium	Rh	104
Rubidium	Rb	85
Ruthenium	Ru	104
Samarium	Sm	150
Scandium	Sc	44
Tantalum	Ta	182
Thallium	Tl	204
Thorium	Th	232

Name.	Symbol.	Atomic Weight.
Titanium	Ti	48
Tungsten (Wolframium)	W	184
Uranium	U	240
Vanadium	V	51
Ytterbium	Yb	173
Yttrium	Y	90
Zirconium	Zr	90

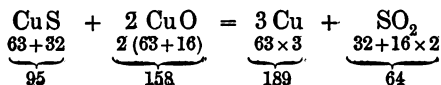
Use of Chemical Symbols. The names of the elements are often rather long, and to write them in full every time the element is referred to is troublesome. To obviate this, chemists have invented a kind of shorthand by which each element is represented by one or two of the principal letters of its name, as H for hydrogen, Cl for chlorine, &c. The sign or *symbol* is frequently derived from the Latin name of the element, as Au for gold (Latin, *aurum*), Pb for lead (Latin, *plumbum*). All the symbols are shown in the above table of the elements.

Chemical compounds are briefly indicated by grouping together the symbols of the elements of which we know the compound to consist. A small figure *below* and to the *right* of a symbol indicates how many atoms of that element are contained in the single molecule which the symbol or group of symbols represents. Thus, one molecule of the compound known as water is represented by the letters H_2O , which tell us that this molecule consists of two atoms of hydrogen combined with one atom of oxygen. We then say that H_2O is the chemical *formula* for water. A large figure in front of such a group of symbols tells us how many molecules are indicated: thus, 4 H_2O , stands for four molecules of water.

Atomic Weights and their Uses. The atoms of the different elements differ in weight. The lightest of all the elements is the gas known as hydrogen, and hence (to avoid fractions as far as possible) we commence with the atom of hydrogen, and represent its weight by the number 1. Oxygen gas is sixteen times heavier than hydrogen; and hence the atomic weight of oxygen is said to be 16. The atomic weights of all the elements have

been calculated with great care, and are shown in the table above.

Chemical Equations. Knowing the atomic weights, and also the number of atoms (or molecules) taking part in any chemical change or reaction, we can easily calculate the *weights* of all the substances concerned in the reaction. Thus, the following expression or *equation* (so styled because the number of atoms on the right and on the left of the central sign of =, are equal in number) shows six atoms on each side, and the numbers indicate the *parts by weight* which take place in the reaction:—



That is, 95 parts by weight of copper sulphide combine with 158 of copper oxide, to produce 189 parts by weight of copper and 64 of sulphur dioxide.

For “parts by weight” we may substitute pounds, or tons, or kilogrammes, &c., it matters not which, the *proportion* will still hold true.

It is evident that the power of being able to represent by such equations each chemical change that takes place during a metallurgical operation is of great value, because it gives us the precise quantities of the various substances by weight which take part in the change. It tells us the exact proportions in which to mix our materials; and the results which we ought to obtain.

CHAPTER II.

METALS: AND THEIR PHYSICAL PROPERTIES.

Some Physical Properties of Metals. Since the introduction of the spectroscope, and the perfecting of analytical methods, many new metals have been added to the list of the metallic elements.

Only one metal is liquid at ordinary temperatures; this is mercury, which solidifies only at -39° C. Bismuth, tin, and lead melt below a red heat; silver, copper, and gold become liquid at the temperature of an ordinary furnace; while platinum, osmium, and iridium, can only be melted by special means, and at extremely high temperatures. As a rule alloys are more fusible than the most fusible of their constituents.

Several metals volatilize, or pass into the gaseous state, at comparatively low temperatures; but there is no definite relationship between fusibility and volatility. When arsenic is heated, it passes from the solid to the gaseous state without first passing through the intermediate or liquid stage; but if it is heated *under pressure* it fuses before volatilizing. All metals volatilize if heated to a sufficiently high temperature; thus silver has lately been purified for research purposes by distilling it in lime crucibles by means of the oxy-hydrogen blow-pipe flame.

Many metals become *plastic* or pasty when still much below the temperature at which they actually melt; thus wrought iron, steel, lead, gold, silver, and copper all pass through a pasty state previous to fusing, and can then be *welded* or hammered together.

Different metals have very different capacities for heat; and the ratio of the quantity of heat required to raise one pound of any metal through one degree, as compared with that required to raise the same weight of water through one degree, is called the *specific heat* of the metal.

Specific Gravity of Metals. The specific gravity of a body is the weight of the body compared with the weight of an equal volume of distilled water. Thus a cubic inch of copper weighs nine times as much as a cubic inch of water; the specific gravity of copper is therefore said to be 9.

To determine the specific gravity of a metal—1st, weigh the metal in air; 2nd, weigh it in water; it will be found to lose weight. The loss of weight represents the weight of a piece of water equal in volume to the metal. Lastly, divide the loss of weight in water into the weight

of the metal in air, and the specific gravity of the metal is obtained. Thus:—

Weight of metal in air.....	= 268 grains.
Weight of metal in water.....	= 240 grains.
Loss of weight in water (or the weight of an equal volume of water).....	= 268 - 240 = 28 grains.
∴ The Sp. Gr. of the metal.....	= $268 \div 28$ = 9.57. ANSWER.

The specific gravity of metals varies from 0.6 for lithium, to 22.8 for iridium. The Sp. Gr. of a metal varies slightly according to the treatment which the metal receives. Hammering a metal as a rule *increases* its density and specific gravity. By *compression* between dies the Sp. Gr. of gold is increased from 19.25 to 19.37.

The process of wire-drawing *diminishes* the Sp. Gr. of a metal in most cases. Unannealed copper has its density lessened from 8.9 to 8.8 after being drawn out; but annealed copper *increases* in density from 8.8 to 8.95 on being drawn into wire.

Annealed Copper. The process of annealing causes the molecules to move a little further apart; and the "drawing" into wire of such copper produces a closer approximation of the molecules, and therefore an increase in density.

When in the liquid state, the Sp. Gr. of a metal is generally *less* than when in the solid state (bismuth, however, is an exception to this rule). The following table gives the comparative Sp. Gr. of five metals when in the two states:—

	SPECIFIC GRAVITY.	
	Liquid.	Solid.
Lead	10.37	11.4
Tin.....	7.02	7.5
Zinc.....	6.48	7.2
Silver	9.5	10.57
Bismuth.....	10.05	9.82

Varieties of Fracture. The character of the fractured surface of a metal is frequently a good guide as to its physical properties. Gold, silver, copper, platinum, and arsenic have a finely granular fracture. Zinc, antimony, bismuth, and spiegeleisen possess a crystalline fracture; some varieties of iron present a granular fracture, while others show a fibrous fracture. Lead has a coarse, well-developed columnar fracture; and this may readily be obtained by heating a small ingot of lead until it is about to melt, withdrawing it from the furnace, and tapping it smartly against a brick; the lead then comes apart and exhibits a columnar fracture. The presence of .8 per cent of antimony in lead gives the alloy a finely granular-fibrous structure; and if the percentage of antimony is increased the fracture is very granular.

Malleability. This is the property which many bodies possess in virtue of which they can be hammered or rolled out into thin sheets without cracking. Malleability depends mainly upon softness and tenacity. Gold is the most malleable of all metals; and one grain of this precious metal can be made to cover 56 square inches.

The malleability of a metal is much influenced by the presence of impurities and of other metals, the tendency of the impurities being to lessen the malleability. Temperature sometimes affects malleability; if a piece of copper is hammered when cold it becomes hard; its malleability being restored after annealing at a red heat. The relative malleability of the principal metals is as follows, the most malleable being placed first:—Gold, silver, copper, tin, platinum, lead, nickel, zinc, and iron.

Ductility. This is a property possessed by certain metals which enables them to be drawn out into wire. It is the permanent extension of a metal by traction. The greatest length of wire which can be obtained without breaking from a given weight is a measure of the ductility of a metal. As a metal increases in length, its sectional area is reduced; this being effected by causing the metal to pass through a series of perforated steel plates, the first plate having the largest hole; and the

holes in each successive plate decreasing regularly in diameter. During the process of elongation the metal must be repeatedly *annealed*, or it will become brittle. Gold, silver, and platinum are the most ductile of all metals.

Tenacity. This is the property possessed in a greater or less degree by all solid bodies which enables them to resist any force which tries to pull their molecules apart.

In metals both tenacity and elasticity may be increased by hammering and rolling. Tenacity is measured by seeing what weight a body can bear without being torn asunder. Bars of metal having equal sectional areas are taken, and a gradually increasing weight is applied at one end until the rupture occurs. A bar of steel, one square inch in section, will just support a weight of 50 tons; a bar of wrought iron of the same diameter can support only 25 tons. Steel, therefore, possesses twice the tenacity of wrought iron.

Tenacity may vary in degree in the same metal, being greater in fibrous iron than in crystalline iron.

Toughness. A body which is flexible without being brittle, and which yields with difficulty to a force without breaking, is said to possess the property of *toughness*. Malleable iron, copper, gold, and lead are very tough.

Softness of Metals. As used in metallurgy, this term is solely applied to those metals which are easily cut by the penetrating action of such a substance as steel. Thus lead is considered to be soft since it does not require the application of much force to cut it, with, say a knife. In soft bodies it is clear that the cohesive or attractive force between the molecules is not so great as in those which are hard, iron for example, and so the resistance offered by the metallic particles to their separation is not so great. The softness of a metal always increases with a rise of temperature. This is easily explained on the above principle, as the effect of a rise of temperature is to cause the cohesive force of the molecules of the substance to become lessened.

The following common metals are arranged in their

order of softness, the softest metal being placed first:—Potassium, sodium, calcium, lead, tin, magnesium, aluminium, gold, silver, platinum, copper, iron, nickel, manganese.

From this it is seen that potassium and sodium are the softest of all the common metals, the proof of which is readily forthcoming on cutting them.

Elasticity. Elasticity is that property of matter by virtue of which it requires force to change its bulk and dimensions (the force having to be continued in order to maintain this change); the body resuming its original bulk and dimensions on the removal of the force. The elasticity of a metal is measured by finding the least load by which a *permanent* alteration of form is effected. Practically the elasticity is found by stretching or extending a bar of the metal until it just ceases to resume its original length when released.

The “limit of elasticity” is reached when a rod of the metal is stretched just to its utmost limit without permanent change; this limit being obtained by gradually increasing the pull upon the rod, and releasing it from time to time.

Metallic Lustre. All pure metals possess a peculiar shiny appearance or *metallic lustre*, due to the reflection of the greater part of the rays of light which fall upon their surfaces. But lustre is not possessed by metallic elements alone; the non-metals graphite, diamond, iodine, silicon, boron, &c., are also lustrous.

The lustre of a metal is much increased by polishing, and in some cases by the addition of other elements; thus an alloy of tin and copper possesses a greater lustre than either of these metals alone.

Colour of Metals. The colour of a metal must not be confounded with its lustre.

The rays of light which fall upon the surface of a metal are partly absorbed by the metal, and partly reflected from its surface to the eye. The colour of a metal is due to the nature of the light which is reflected from its surface, and the colour may be intensified by

causing the rays to be repeatedly reflected from several surfaces of the same kind of metal. Thus if a ray of light is reflected ten times from as many polished surfaces of copper, the copper appears to be of a scarlet colour; if reflected ten times from iron, this metal has a violet colour.

All metals are opaque, except when in extremely thin films. A thin film of gold (as gold-leaf) transmits green light.

CHAPTER III.

EXPLANATION OF TERMS USED IN METALLURGY.

"Ore." Ores are the natural mineral substances from which metals can be extracted with advantage. The degree of richness of an ore depends on (1) the value of the metal to be extracted; (2) the amount of the metal present; and (3) on the difficulty attending its metallurgy. Thus tin ores containing only 1 per cent of tin can by proper treatment be easily brought up to 50 or 60 per cent of tin, because of the high density of the ore. Tin ores containing a large proportion of silica would be useless; whilst copper ores containing a large amount of combined sulphur can be successfully smelted even if they contain silica.

Classification of ores:—

1. Simple ores, as argentiferous lead ore; their value depending upon the amount and nature of the gangue associated with them.

2. Refractory ores; those which are difficult to smelt, and which resist the action of reducing agents; as the ores of nickel.

3. Fusible ores; these yield up their contained metals very readily by reason of their low melting-points, as the ore of bismuth (*Bismuthine*, Bi_2S_3).

"Native." This term is employed to denote those elements which occur naturally in the free or uncom-

bined state. Thus gold, silver, copper, mercury, platinum, arsenic, antimony, and bismuth occur "free" in nature, though usually mixed with gangue, &c. Metals in the native state are not always the best adapted for metallurgical purposes. In the Lake Superior district, for example, vast deposits of native copper are found; but either so mixed with gangue (from which it is very difficult to separate the metal), or so expensive to cut and hew out of the rock, that it is found to be more profitable to mine and extract the sulphide of copper ore.

Veinstuff, or Gangue. This is the useless or undesired material associated with the ore. It may be metallic, earthy, siliceous, or basic; and the composition and amount of the gangue materially affect the quality and value of the ore. Quartz, calcite, barytes, clay, fluor-spar, and chlorite are the chief minerals which constitute the gangue. Ores containing quartz are troublesome to work, as that mineral is difficult to separate by dressing, and is also very infusible.

"Dressing." By this we mean the separating of a useful mineral from its associated gangue by mechanical methods. Thus tinstone occurs intimately mixed with quartz, mica, tourmaline, wolfram, and iron and copper pyrites; and the *tinstuff* as raised from the mines does not contain more than 1 per cent of *tinstone*. But by taking advantage of the high specific gravity of tinstone, which is 6.8, it may be separated from the associated useless gangue or veinstuff by washing in water, the tinstone sinking to the bottom of the vats while the lighter minerals forming the gangue are carried on and washed away. By repeated "dressing" the proportion of tinstone may be raised to over 50 per cent.

Reduction: or the act of "Reducing". When an element is isolated from the compound which contains it, the compound is said to be "reduced to the metallic state". The substances which effect the reduction are termed *reducing agents*.

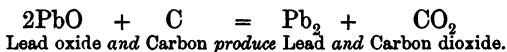
A high temperature is sometimes required before re-

duction can occur, the reduced metal being fused; but occasionally reduction without fusion takes place. Oxides are more easily reducible than other compounds: metallic ores are therefore usually roasted to convert them into oxides, if they are not already in that state.

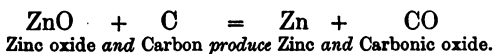
The reducing agents commonly employed are carbon, carbonic oxide, hydrogen, hydrocarbons, and (more rarely) iron, manganese, and lead.

The most active reducing agents are those which contain the greatest amount of carbon; thus wood and peat have a less reducing action than coke, and coke has less than charcoal. And the purer the form of carbon, the greater is its reducing power.

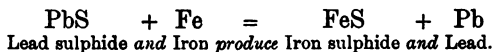
When lead oxide (PbO) is reduced by carbon, carbon dioxide is produced, just as when carbon is burnt in air. Thus:—



If the reduction of an oxide requires a high temperature, the carbon dioxide which is first formed is reduced to carbonic oxide by the incandescent carbon present. For example, when zinc oxide is reduced to metallic zinc, thus:—



Metallic iron reduces many sulphides, owing to the affinity it has for sulphur. Thus galena or lead sulphide (PbS) is readily reduced to lead by means of iron at the temperature of an ordinary furnace, thus:—



Smelting. This is the operation of reducing ores and metallic compounds by heat, in order to extract the useful metals contained in them. Smelting operations are conducted in furnaces; and in the case of iron, copper, &c., are very complicated and involve large and costly

appliances. Mercury, bismuth, and zinc ores, however, are smelted with little difficulty, the ores being very reducible and easy to manipulate.

The nature of the smelting processes depends upon the composition and degree of refractibility of the ores to be treated. Ores containing gangue require a preliminary "dressing" before being smelted, or require to be calcined or roasted.

Regulus. The term "regulus" is exclusively applied to a metallic sulphide, the sulphide having been formed by the chemical combination of the metal with sulphur at

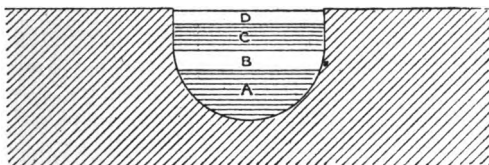


Fig. 1.—A, Lead. B, Speise. C, Copper regulus. D, Slag.

an elevated temperature. During the smelting of copper ores, the copper is converted into a sulphide or *regulus*, from which the sulphur is removed and metallic copper so obtained.

Speise. This term is applied to a metallic arsenide, the metal having combined with arsenic at a comparatively high temperature. Thus nickel-speise is an arsenide of nickel frequently produced during the smelting of nickeliferous copper ores; such a speise very often also contains sulphur, copper, iron, and cobalt.

The following table shows the average composition of a nickel-speise:—

Nickel,	...	...	...	45% to 47%
Cobalt,	...	...	...	4 " " 6 "
Iron,	...	...	...	8 " " 10 "
Copper,	...	...	...	1 " " 1.5%
Arsenic,	...	...	...	33 " " 36 "
Sulphur,	...	...	...	1 " " 2 "

In the smelting of complex ores containing lead, copper, nickel, and cobalt, the molten metals and metallic compounds arrange themselves in the vessel or receptacle into which they are poured in the order of their specific gravities (see fig. 1). Lead therefore occupies the lowest level, being covered with nickel-cobalt speise, which in its turn is covered with copper regulus; the regulus lastly having a layer of slag resting upon it.

Roasting. The operation known as "roasting" is often employed to oxidize an ore before it is smelted, or to drive off carbonic acid gas from it; and roasting always involves a chemical change and rearrangement of the elements composing the ore. Thus if iron carbonate is roasted, we obtain ferric oxide; carbon dioxide being evolved. Ores which contain sulphur or arsenic are roasted to oxidize them into oxides, arsenides, sulphates, &c. In *calcination* we have simply the burning off of the volatile products.

The object both of roasting and of calcining ores is not only to produce a chemical rearrangement and burning away of volatile products, but also to render the ores spongy and porous, in order that reducing agents may act upon them more rapidly and powerfully.

Roasting is generally used to get rid of sulphur, arsenic, and antimony; and ores of iron, copper, cobalt, nickel, and zinc are almost invariably subjected to this process. Roasting is now usually conducted in reverberatory furnaces, the ore being spread over the hearth and occasionally turned over and exposed to the air; when the roasting is to be complete and rapid the ore must be spread out in thin layers. The more fusible the ore the lower must be the temperature of roasting, except towards the end, when it is sometimes necessary to raise the temperature in order to fuse the mass.

When the roasting is prolonged so that all the volatile products present are driven off, the ore is said to be "sweet" or "dead".

Distillation. This is the name applied to the process of driving off by heat a volatile substance in the form of

gas or vapour, and then condensing the vapour to a liquid or solid in, and by means of, a cooled receiver. Mercury and zinc are always extracted from their respective ores and separated from other metals by simple distillation processes. The heating is effected in vessels

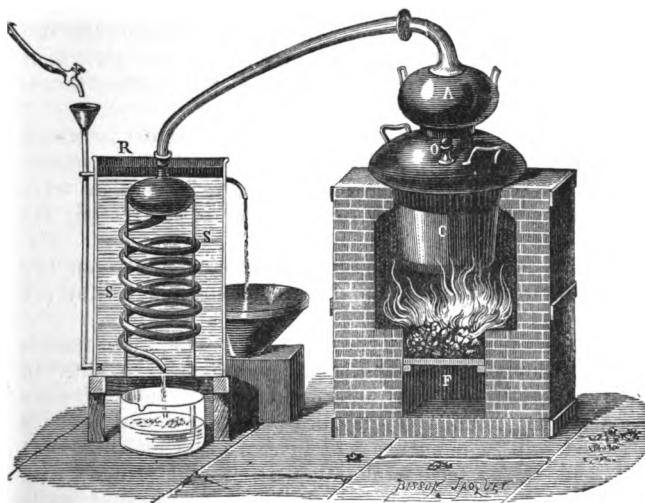


Fig. 2.—Apparatus for Distillation. c, Still; s, s, Worm or condenser. The worm is contained in a vessel r, through which cold water passes.

called *stills* or *retorts* (see c, fig. 2), while the cooled receiver is termed a *condenser*.

Sublimation. When a solid body is heated, and it does not melt to a liquid but at once passes into the state of a vapour or gas (which vapour may be subsequently condensed, and so the solid again obtained), the solid is said to have been “sublimed”, or to have undergone the process of “sublimation”. In practice this term is not always strictly used in the above sense. Any metal or compound obtained by submitting ore, &c., to a high temperature in a crucible or other vessel, and then causing the vapours given off to condense upon the

sides or top of the same vessel, is said to have been obtained by the process of sublimation. This holds true even if the solid heated passed through the liquid condition before its vapour was given off.

Thus arsenic is obtained in the metallic state by placing its ore in an iron vessel called a "subliming pot", to the top of which a flat or concave cover is fitted. On the application of heat, vapour of arsenic is given off which condenses on the cool cover of the pot. Arsenic therefore can be obtained by sublimation.

If the vapours are led from the pot or retort in which they are formed to a distinct vessel or chamber before they are condensed (as is the case, for instance, with mercury), then the ores, or whatever is so treated, are said to be "distilled".

There is a distinct difference, therefore, between the processes of sublimation and distillation, though they are analogous to one another.

Liquation. This is the method by which two metals in an alloy may be separated, by heating the alloy to only a little over the melting-point of its most fusible constituent. Thus if an alloy of copper and lead is heated to a temperature a little above the melting-point of lead, the latter metal liquates out and brings away with it any silver or gold that may be in the alloy, while the copper remains unmelted. Zinc can similarly be separated from iron; and under certain circumstances zinc can even be parted from lead by this method. In the same manner the sulphides of antimony and of bismuth are liquated out from the gangue in which they usually occur.

Scorification. "Scoriæ" are the silicates of useful metals produced during smelting operations, and are termed plumbiferous, cupriferous, or ferruginous, &c., according as the predominant base is lead, copper, or iron oxide. "Slags" are the silicates of earthy metals, as alumina, lime, potash, &c., and contain no useful metals. "Scoriæ", on the other hand, do contain useful metals, which may be extracted at a high temperature.

Scorification is the process of converting the foreign substances present in a metallic compound or alloy into a scoria, and it is frequently resorted to in the separation of silver from lead and antimony. This is effected on a small scale by heating the alloy in a fire-clay dish termed a scorifier, a scoria of silicate and antimoniate of lead being produced, and metallic silver remaining.

Amalgamation. An amalgam is a compound of mercury with other metals. Natural amalgams of mercury and silver occur at Almaden in Spain, and in Bavaria; gold amalgam has also been found in South America and in California. The term *amalgamation* is applied to those processes in which gold, silver, and other metals are extracted from their ores by the aid of mercury, the mercury forming an alloy with the gold or silver. On afterwards distilling the alloy, the mercury is driven off as vapour, leaving behind the precious metals in a pure state. The mercury vapour is then cooled, when the metal returns once more to the liquid state, and can then be used over and over again.

Cupellation. This is a method chiefly used for extracting silver from its alloy with lead, though it may also be used for the separation of gold from a similar alloy. The lead which is to be desilverized is placed upon the bed or hearth of a special kind of reverberatory furnace, called a "cupellation furnace" (see fig. 3). This bed, *c*, consists of bone-ash, or a mixture of bone-ash and marl. In order to prepare it, a quantity of burnt bones is taken and reduced to the state of powder. This powder is then moistened with water containing some alkali, and the paste so formed is pressed and beaten down into an oval-shaped iron casing or "test ring". Gutters are made in the side of the bone-ash vessel, *c*, thus formed, and this constitutes what is known as a "cupel" or "test". This cupel is usually made about 4 ft. long, 3 ft. wide, and some 8 in. deep. The cupel is then slowly dried in a cupel chamber, and introduced into the cupellation furnace. A charge of lead is placed on the heated cupel, which is then brought gradu-

ally (so as to avoid its cracking) up to a high temperature. When the lead is melted a blast of air is made to play on its surface. The lead is by this means oxidized or changed into litharge (PbO), which being in a molten state is readily absorbed by the porous bone-ash, or is run out by means of gutters in the side of the cupel. Any impurities which may be present are also absorbed by the cupel. The silver is not in the least changed,

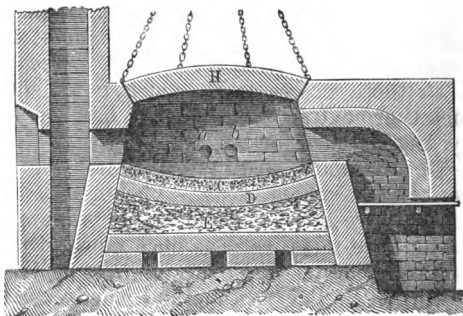


Fig. 3.—Cupellation Furnace. d, Hearth. c, Porous coating. h, Movable lid.

since it does not combine with oxygen directly at any temperature. Accordingly this precious metal is not absorbed, and remains behind on the surface of the cupel in a pure condition.

If a gold-lead alloy is cupelled, the operation is precisely the same; the lead becoming oxidized, and being so got rid of, whilst the gold remains behind in a molten state on the cupel, and is then tapped off into moulds.

A cupel having the dimensions stated would serve for some 8 tons of lead, when it would have to be replaced by a new one.

CHAPTER IV.

SLAGS AND FLUXES: FURNACES, CRUCIBLES, FIRE-BRICKS, ETC.

General Properties of Slags and Fluxes. A *slag* is the refuse or ashy matter obtained by the fusion of the *flux* with the gangue of the ore. In copper-smelting, first the melted metal (at the bottom), then the speise, next the regulus, and, lastly, the slag, are found superimposed on one another in the order named (see fig. 1), this separation being due to the differences in density of the various substances. Slags are the silicates of earthy metals, and from a metallurgical point of view are valueless. They are divided into *hydrous* and *anhydrous* according as to whether they are combined with water or not.

All slags contain silica (SiO_2), and they are termed *acid* or *basic* according as the percentage of silica present in them is great (acid) or small (basic).

The silicates of which slags are formed are classified as monosilicates, bisilicates, trisilicates, &c. A monosilicate contains 2 atoms of oxygen in the base and 2 atoms of oxygen in the acid. Thus the silicate of iron, $2\text{FeO}.\text{SiO}_2$, is a monosilicate. A bisilicate contains 1 atom of oxygen in the base and 2 atoms of oxygen in the acid, as $\text{CaO}.\text{SiO}_2$, calcium silicate. Kaolin, or porcelain clay, $\text{Al}_2\text{O}_3.2\text{SiO}_2$, is a trisilicate of alumina.

Slags vary very considerably in structure, ranging from glassy to stony types; rapid cooling producing a glassy slag, and slow cooling a stony or crystalline one.

Slags containing ferrous oxide, as $2\text{FeO}.\text{SiO}_2$ and $3\text{FeO}.\text{SiO}_2$, are used to remove carbon from cast-iron, and sometimes to remove sulphur and phosphorus from the same metal.

A *flux* is something added to make the gangue fuse or flow at a lower temperature. Barytes, lime, quartz, magnesia, fluor-spar, and iron-oxide act as fluxes. The flux to be employed will depend upon the composition

of the gangue; if the gangue is siliceous the flux must be basic (the silica of the gangue then having plenty of base with which to combine); if it is basic the flux must be siliceous.

Slags containing zinc-oxide are very infusible; but if iron-oxide is added a fluid slag is formed, even if 20 per cent of zinc-oxide is present. If the gangue is calcareous or magnesian, silica must be added as a flux. Lime is an excellent flux for a siliceous gangue; but still better is a mixture of lime and magnesia. In the metallurgy of iron, sulphur and phosphorus are always troublesome; and care must be taken that the flux chosen for iron ores is free from these injurious elements.

External Characters, and Fusibility of Slags.

As mentioned above, slags exhibit every gradation, from perfectly stony to perfectly glassy conditions; some are pumiceous, others compact and flinty.

Nearly all the structures found in ordinary vitreous igneous rocks have their exact counterpart in slags. Many crystalline minerals have been detected in slags, the most common being augite and olivine. Slags also exhibit a banded structure, due to the motion of the slag when in the fluid state. They range in colour from black to white; some are dark-green, others gray; and some have a beautiful blue colour. These blue slags have their exact counterpart in nature—in the blue mineral lapis-lazuli. The slags termed basic silicates are usually dark-green.

Some slags are perfectly fluid when melted; others are very pasty, and almost infusible. The fluidity of a slag depends simply upon the composition of the silicates of which it is composed. The most fusible silicates are those produced by the alkali metals, sodium and potassium. A simple silicate (*i.e.* a silicate containing only one base) is *always* less fusible than a silicate containing two or more bases. Thus the silicates of lime and magnesia *separately* are much less fusible than the double silicate formed by the chemical combination of the two; it is therefore very desirable to form *double* silicates in

blast and other furnaces. Bisilicates pass gradually from the solid to the liquid state, and are generally plastic. Basic silicates pass rapidly into the liquid condition, and soon cool after they have solidified. The presence of alumina makes a great difference in the fusibility of a slag. A slag containing 23 per cent of silica, 70 per cent of lime, and 7 per cent of alumina will fuse; but a slag containing 31 per cent of silica, 53 per cent of lime, and 16 per cent of alumina is infusible. Alumina often takes the place of silica, and then we get aluminates of iron, of calcium, &c. Alumina thus acts as an acid in this case. Slags consisting of simple aluminates are extremely infusible; the aluminate of magnesium, for example, does not melt before the oxyhydrogen blow-pipe. Double aluminates are more fusible.

Silicates containing ferric oxide, Fe_2O_3 , are not so fusible as the ferrous silicates. This is the reason why iron slags in reverberatory furnaces become more pasty as they get oxidized, because the ferrous oxide is slowly changed into ferric oxide.

Utilization of Slags. Slags are frequently ground to a powder and manufactured into hydraulic cement. Many articles ordinarily made of earthenware can be made of slag, which by suitable additions makes a fairly good glass.

Basic slags containing combined phosphorus are now ground to powder and largely employed in agriculture as manures.

"Slag wool" is used as a boiler packing, a jet of steam at high pressure being forced into a stream of fluid slag, which then blows out into a wool-like material.

Bricks are often made of slag, but they easily disintegrate.

Natural Refractory Materials employed in the construction of Crucibles, Retorts, Furnaces, &c. In furnaces where a high temperature is required, the materials forming the furnace itself must be capable of resisting the heat; and of withstanding also the corroding action of the metallic, slaggy, and gaseous matter

which are being formed. They must also in many cases be able to withstand great pressures.

The refractory materials employed may be—

1. Acid, as silica, and siliceous fire-clays.
2. Neutral, as graphite, and some fire-clays.
3. Basic, as magnesia and lime.

The natural refractory materials employed by the metallurgist are:—

(1) Silica or quartz; this mineral only fuses in the oxyhydrogen blow-pipe. It is generally used in small lumps, with just enough cement to bind the whole together.

(2) Siliceous sands and grits; such as those occurring in the Vale of Neath, and at the Puy de Dôme, Auvergne.

(3) Fire-clays. These form the underclays of many coal-fields: they vary in their composition; but all contain silica and alumina. Those fire-clays which contain ferric oxide easily fuse at high temperatures, and are useless for furnace-building, &c. The pure fire-clays are manufactured into bricks, crucibles, muffles, &c.

(4) Ganister. This highly refractory siliceous material takes the place of the underclay in certain parts of the Yorkshire coal-field. The following is an analysis of two samples of ganister:—

		1st.	2nd.
Silica,	... ..	89·5 per cent.	93·5 per cent.
Alumina,	... ..	4·8 "	4·2 "
Ferric oxide,	... ..	0·88 "	0·8 "
Lime,	... ..	0·60 "	0·2 "
Magnesia,	... ..	0·1 "	
Potash,	... ..	0·9 "	

Ganister is employed for lining the Bessemer converters employed in the "acid process"; and for furnace bottoms.

(5) Natural oxides of iron; as magnetite, hematite, and ilmenite; these oxides are extremely useful for lining puddling furnaces.

(6) Dolomite; a double carbonate of calcium and magnesium; this basic substance is highly refractory,

and is largely used for lining the Bessemer converters employed in the "basic process".

(7) Magnesite or magnesium carbonate; it is made into bricks and used in puddling furnaces where the material is likely to be extremely corrosive.

(8) Bauxite is a hydrate of alumina containing variable quantities of ferric-hydrate. It has the following composition:—

Alumina,	52.0 per cent.
Ferric oxide,	27.6 . "
Water (combined),	20.0 . "

Bauxite is highly refractory, owing to the large amount of alumina it contains. It is mixed with about three per cent of clay and six per cent of graphite powder; and is then used for protecting the furnace-bed from the corroding action of metallic scoriæ in Siemens' "open hearth" furnaces.

(9) Graphite; this is a form of crystalline carbon, chiefly obtained from Ceylon; and is very largely used for making plumbago or graphite crucibles.

Crucibles.—Graphite, Black-lead, or Plumbago Crucibles. Crucibles are usually made of fire-clay, or of a mixture of fire-clay and graphite (see figs. 4, 5, and 6). When fire-clay crucibles are simply *lined* with graphite or some other form of carbon, they are said to be "brasqued".

Fire-clay consists of a hydrated silicate of alumina; and kaolin is looked upon by many chemists as the basis of all clays. Pure kaolin has the following composition:—

Silica,	40.5 per cent.
Alumina,	45.0 . "
Water,	14.5 . "

All raw clays become pasty on the addition of water, and may then be moulded into any shape; they lose this plasticity if heated strongly, and contract at the same time.

ANALYSIS OF A GOOD FIRE-CLAY.

Silica,	...	...	...	50.0 per cent.
Alumina,	...	...	...	32.6 "
Potash,	...	...	...	2.3 "
Soda,	...	...	...	a little.
Lime,	...	...	...	0.3 per cent.
Magnesia,	...	...	...	0.4 "
Ferric oxide,	...	...	...	3.5 "
Water,	...	...	...	9.7 "

ANALYSIS OF A BAD FIRE-CLAY.

Silica,	...	...	...	50.0 per cent.
Alumina,	...	...	...	23.0 "
Potash,	...	...	...	4.2 "
Lime,	...	...	...	0.17 "
Magnesia,	...	...	...	1.2 "
Ferric oxide,	...	...	...	2.4 "
Water,	...	...	...	5.8 "

A crucible should be tough and elastic; it must be able to resist high temperatures, and must not soften; it should not be tender when hot; and it ought to be able to resist sudden alterations of temperature; and also to withstand the corroding action of melted oxides.

Crucibles of all kinds must be carefully dried and annealed before using. It is usual to mix ordinary plastic clay with previously burnt clay, and to add a little coke to the mixture; this makes a good material for crucibles (see fig. 5).

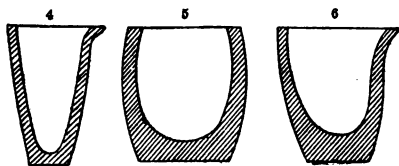
Plumbago or "black-lead" crucibles resist sudden and extreme changes of temperature without breaking up or fusing; and may be used several times. The plumbago is ground up and mixed with finely powdered fire-clay; water is added; and the whole is placed in a mixing mill. It is then left for some time to "mellow", and is afterwards made into crucibles (see fig. 4).

The following is an analysis of an English "black-lead" crucible:—

Silica,	...	...	...	50 per cent.
Alumina,	...	...	...	20 "
Ferric oxide,	...	...	...	1.5 "
Graphite,	...	...	...	25.5 "
Lime,	...	...	...	0.55 "

For special purposes, crucibles are also made of hard coke obtained from gas retorts.

Lining Crucibles with Carbon. Fire-clay crucibles are frequently lined with carbon; for certain purposes, simply rubbing powdered charcoal over the inside of the crucible is sometimes sufficient. If a thick lining is required, the powdered charcoal is mixed with tar or treacle to render it adhesive, this mixture being plastered over



Figs. 4, 5, 6.—4, French crucible. 5, Cornish do. 6, London do.

the inside of the crucible with a small stick. Such crucibles are termed “brasqued”.

Classification of Furnaces.—The Modes of Producing and Utilizing Heat in the various forms. Various types of furnaces are employed by the metallurgist. The two principal parts of a furnace are the interior or fire-resisting part; and the exterior or binding part. The exterior of a furnace is made of badly conducting materials in order to avoid undue loss of heat by conduction and radiation. The interior is made to suit the conditions under which it is to be used; the materials composing the interior varying in composition as to whether a reducing, an oxidizing, or a neutral atmosphere is to be produced.

Furnaces can be divided generally into three classes:—

(1) Those without an independent hearth; the ore and fuel being mixed together, as in blast-furnaces.

(2) Those with independent hearths; but in which the ore is separated from the fuel; as in reverberatory furnaces.

(3) Furnaces in which the ore is separated both from the fuel and from the products of combustion. The

retort-like furnace in which zinc is distilled is an example of this class.

In whatever class of furnace employed, *heat* is necessary for initiating and maintaining the chemical changes and fusion of the ore or metal contained in the furnace. In every case some form of fuel is employed to obtain the necessary heat; in the Bessemer converter the temperature is maintained by the burning of the impurities contained in the metal, and even by the burning of the metal itself.

Heat is produced by "combustion", that is, by the chemical union of different kinds of matter; and in order to obtain the combustion of fuel, and to produce the maximum quantity of heat, oxygen gas is practically necessary.

In the blast-furnace, charcoal, coal, or coke is mixed with the ore; and the combination of these substances with oxygen gas (from the air) generates sufficient heat to smelt the ore and to liquefy the metal. The temperature of the furnace is raised by forcing a blast of cold air into the furnace; but is proportionally increased if the injected air is previously heated.

Gaseous fuel has of late years been largely introduced; the gases being obtained by heating solid fuels rich in hydrogen (which then yield carbonic oxide and gaseous hydrocarbons). The hot gases thus obtained are mixed with air and burnt in the furnace; and are advantageous in that they leave no cinders, while by their use the temperature of the furnace can be very easily regulated. In reverberatory furnaces the flame from the fuel is deflected by the arched sloping roof upon which it impinges on to the metal placed upon the hearth beneath.

Principle of the Siemens and other analogous Furnaces. In reverberatory furnaces solid fuel does not come into contact with the ore or metal placed upon the hearth, the necessary heat being obtained by burning coal in a separate grate. The gaseous products formed during the combustion of the coal ignite and burn over the hearth of the furnace, melting the metal and initiating the chemical changes which take place.

In **Siemens' Regenerative Furnace**, and in those analogous to it, the waste heat from the furnace is "regenerated" or restored to the furnace together with combustible gases obtained by heating solid fuel in a special grate termed the "gas-producer".

The Siemens furnace is of the reverberatory type, having a dome-shaped roof, and stands above four arched brick chambers which are nearly filled with fire-bricks

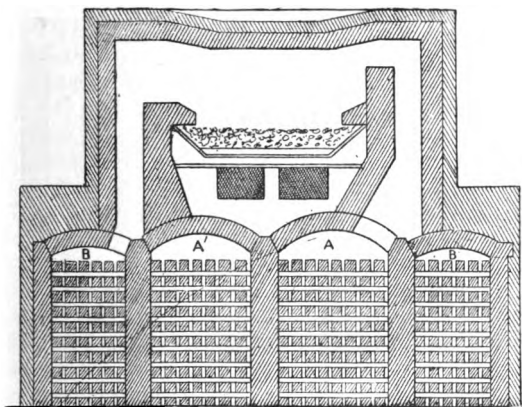


Fig. 7.—Siemens' Regenerative Furnace. A and A', Chambers to heat gases
B and B', Chambers to heat air.

stacked regularly, so as to form an open fret-work; A, A' being the regenerator chambers for gas, and B, B' those for air. Flues pass from each end of the furnace to the chambers to admit gas and air. The waste gases from the furnace have a high temperature, and are caused to pass through two of the chambers. As they traverse the channels between the brickwork they give up their heat to the bricks, which become intensely hot. The direction of the escaping waste gases is now reversed by means of a valve, and they are caused to pass through the other two chambers, the brickwork of which is thus likewise heated (see fig. 7).

Gas from the "producer", and air from the outside,

are now passed through the two chambers heated first; the gas traversing one chamber A', the air the other chamber B; and (receiving heat from the brickwork) they enter the furnace at a high temperature, there combining and producing the heat necessary for melting the metal.

After a time the brickwork of these two chambers has yielded up most of its heat to the gas and the air; when this is the case the direction of the waste gases is again reversed, and more gas and air pass through the second

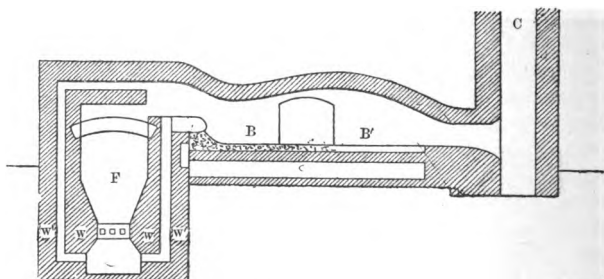


Fig. 8.—Boétius Furnace. w, w', Hollow walls. B, B', The bed. r, Fireplace. c, The chimney.

series of heated chambers A and B' and meet at the furnace. The reversing of the direction of the currents of waste gas, gas from the producer and air, goes on continuously, two of the chambers being heated while the other two are yielding up their heat or cooling. It will be noticed that the direction taken by the waste gas is exactly opposite to that taken by the gas from the producer and the air.

By regulating the supply of air, either an oxidizing, a neutral, or a reducing atmosphere can be produced in the furnace at will. The Siemens regenerative furnace is the most important of those furnaces in which gaseous fuel is employed.

The **Boétius Furnace** is not a regenerative furnace. In this form of furnace the walls w, w' of the gas-producer are made hollow to admit air, which thereby becomes heated before coming into contact with the gas employed

for producing heat (see fig. 8). The working part or hearth of this furnace is directly attached to the gas-producer.

Gas-producers. These are special appliances for generating gaseous fuel from solid fuel, and are constructed with or without a blast of air; steam being largely used along with the air passed in for combustion.

The ordinary "producer" is a rectangular or circular chamber lined with fire-brick (see fig. 9). One side is formed of iron plates lined with fire-brick, and has a step-grate B provided with wrought-iron grate bars. Slack is charged in through a hopper D at the top of the chamber, and incomplete combustion takes place, producing certain combustible gases, which pass through a flue or wrought-iron pipe E into the regenerator. The chief

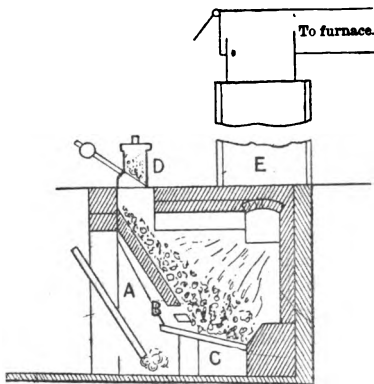
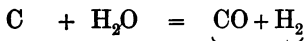


Fig. 9.—Siemens' Gas-producer.

gas formed is carbonic oxide; but when a jet of steam is introduced into the "gas-producer", decomposition of the steam occurs, and a mixture of carbonic oxide and hydrogen is formed, which is termed "water-gas":—



Carbon and Steam produce Water-gas.

This gaseous mixture is much more combustile and produces a much higher temperature than carbonic oxide alone. It passes from the "producer" into the furnace.

Fire-bricks. Fire-bricks are made of some refractory material which must be capable of withstanding a

high temperature without softening. Such bricks must also be able to resist corroding agents, and must not crack or "frit" on sudden changes of temperature. It is further important that they should not crumble when subjected to pressure.

Dinas Bricks are made from a siliceous grit which occurs in the Vale of Neath, and when dry have a pale yellowish-white colour. A little lime is mixed with the powdered grit to cause it to adhere together, the bricks being baked at a high temperature for seven days.

COMPOSITION OF DINAS BRICK.

Silica, ...	...	...	...	98.3	per cent.
Alumina, ...	...	...	...	0.7	"
Ferric oxide, ...	...	...	...	0.18	"
Lime, ...	...	...	...	0.22	"
Potash, ...	...	...	...	0.14	"
Water, ...	...	...	...	0.40	"

These bricks slightly expand on being heated; and are very valuable for the arches of reverberatory furnaces, the whole consolidating into a solid mass at a high temperature. The bricks must be perfectly dry when set; it is therefore usual to heat the bricks before building them up, using a cement similar in composition to the bricks, and to raise the temperature of the furnace gradually.

Devonshire Bricks have the following composition:—

Silica, ...	...	...	...	75.0	per cent.
Alumina, ...	...	...	...	21.2	"
Ferric oxide, ...	...	...	...	1.9	"
Lime, ...	...	...	...	0.4	"
Magnesia, ...	...	...	...	3.7	"
Potash and Soda, ...	...	...	...	0.8	"

Styrian Bricks are nearly as good as Dinas bricks; and are made of silica, with just sufficient fire-clay to bind the mass together.

Bauxite (an impure form of alumina, $\text{Al}_2\text{O}_3 \cdot \text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$) is sometimes made into fire-bricks, and when containing about 6 per cent of graphite these bricks are practically infusible.

CHAPTER V.

FUEL: INCLUDING WOOD, PEAT, COAL, AND CHARCOAL.

Classification of Fuel. Practically only those fuels which contain hydrogen and carbon are available to the metallurgist; for it is the combustion of these two elements that produces the heating or calorific power. Phosphorus and sulphur may also play an important part in the production of heat, as in the Bessemer converter.

Fuel is divided into *artificially-prepared* and *natural fuel*.

The artificially-prepared fuel may be again divided into—(1) Compressed fuels, made by pressing powdered coal and coke into bricks; (2) Dried fuel, as wood, peat, and lignite; (3) Carbonized fuel, as charcoal and coke; (4) Liquid or gaseous fuel, chiefly obtained by the destructive distillation of coal, &c.

All ordinary fuels contain carbon, hydrogen, and also oxygen; but only that hydrogen is available as a source of heat which is in excess of the hydrogen necessary to combine with the oxygen present in the fuel to form water. Cellulose, the basis of woody fibre, contains no available or excess hydrogen (since the hydrogen and the oxygen in it are in the proportion of 2 to 1); cannel coal possesses available hydrogen.

The natural fuels are all of vegetable origin; wood, peat, lignite, bituminous and non-bituminous coal, and anthracite come into this division.

The Calorific Power of Fuel. The calorific power of a fuel is measured by the total amount of heat developed by the complete combustion of 1 lb. weight of the fuel. The calorific power is expressed in units of heat; one unit of heat being the quantity of heat required to raise 1 gramme of water through 1° C. The combustion of the fuel must be complete; all the heat being imparted to raise the temperature of the water. The calorific power of charcoal is 8080; by this we mean that 1 lb. of charcoal completely burnt so as to form carbon dioxide

yields sufficient heat to raise 8080 grammes of water from 0°C. to 1°C. The calorific power of hydrogen is 34,462.

The calorific power of eleven different bodies is given in the following table:—

Charcoal,	8,080
Graphite,	7,047
Diamond,	7,770
Gas carbon,	8,047
Carbon as vapour,	11,214
Crystalline sulphur,	2,262
Fused sulphur,	2,217
Carbonic oxide when burnt to carbon dioxide,	2,403
Hydrogen,	34,462
Methane gas,	13,063
Anthracite,	9,000

Wood. — Elementary Composition of Dry Wood. The basis or groundwork of all vegetable tissues is cellulose, a compound having the formula $\text{C}_6\text{H}_{10}\text{O}_5$.

Woods when dry have a specific gravity varying from .5 to .7. They all contain water even when apparently quite dry; thus air-dried wood often contains as much as 25 per cent of water. The degree of inflammability depends upon the density and dryness of the wood; and upon the amount of resinous matter present. The proportion of ash or mineral matter present in the wood varies considerably, ranging from 1.23 to 10 per cent, and consists of soda and potash; the carbonates of lime, magnesia, and iron; with silica, phosphorus, and sulphur. All woods become ignited at 300°C. ; the whiter and more resinous varieties being combustible at even a lower temperature. Trees from which wood is obtained for metallurgical purposes, should be cut down when containing least sap (*i.e.* in mid-winter), cut into suitable blocks, and stripped of bark. The blocks or logs of wood must be protected from rain, and packed or piled so that air can circulate freely between them.

Wood consists chemically of the elements carbon, hydrogen, and oxygen; together with small quantities of a few other elements which form the whitish ash or mineral matter which remains when wood is burnt.

Air-dried wood has the following composition:—

Charcoal (including 1 per cent of ash) = 40 per cent.

Oxygen and hydrogen (in the proportions in which they form water) = 40 per cent.

Hygroscopic water = 20 per cent.

Peat or Turf.—Composition of Peat. Peat is the product of the alteration of vegetable tissues, being chiefly the result of the continued growth and decay (layer-upon layer) of certain species of mosses. It occurs in beds of from 5 ft. to 30 ft. in thickness either in the lower parts of valleys which are traversed by slow-running rivers, or on exposed table-lands.

Peat varies in colour and appearance from a brown wood-like mass to a dark pitch-like body; its value as a fuel depending on its degree of dryness and compression, its stage of decomposition, and on the amount of ash it contains. Air-dried peat contains about 50 per cent of water; but when heated to 100° or 120° C., it loses all its water; and at 120° C. begins to decompose, forming peat charcoal. Its calorific power, is about 3300, but varies with the amount of water present in it.

Peat when dried contains about 58·6 per cent of carbon; from 4 to 6·5 per cent of hydrogen; and from 32 to 36·5 per cent of oxygen. When burnt it yields from 8 to 10 per cent of ash.

Bituminous Coals. Coal is mineralized vegetable matter. It approximates to lignite on the one hand, and to anthracite on the other; those coals richest in carbon being the most valuable. Coal consists chemically of carbon combined with hydrogen, oxygen, and nitrogen; a small quantity of mineral matter (the ash) is also present.

Bituminous coals are so called from their swelling up into a black bitumen-like mass when heated. They usually burn with a smoky flame. The chief varieties of bituminous coal are:—

1. The non-caking variety.—This burns with a long smoky flame, and yields about 60 per cent of coke, which

consists of a friable crumbly mass, due to the particles not caking together. Owing to this fact, this form of coal burns freely. Its calorific power varies from 8200 to 8300.

2. The caking variety.—This is easily inflamed, and on distillation forms a coherent mass of coke.

3. The caking non-flaming variety.—This does not burn freely, and is not rich in volatile matter. It forms, however, the best coke for metallurgical operations.

Caking Coal. Bituminous coals which yield a coherent mass or cake of coke are termed “caking coals”. They yield from 60 to 68 per cent of coke, are easily inflamed, and burn rapidly with a long flame. Caking coals are well suited for gas furnaces, for they give off from 17 to 22 per cent of coal-gas when heated. Their calorific power is about 8600.

Those varieties of caking coals which are poor in gases, and therefore do not give a long flame when burnt, are the most suitable for coking.

Free-burning Coal. Free-burning coal, as its name implies, is simply coal which burns “freely”, owing to its not caking or cohering together during combustion. The air, with its accompanying oxygen, is then able to pass freely through the coal, which accordingly burns evenly, and without much looking after. It is for these reasons that this variety of coal is so largely used in metallurgical operations.

Anthracite. This variety of coal is of a pure black colour, with metallic lustre, and does not soil the fingers. It decrepitates or breaks up in the fire, and has a calorific power ranging from 9000 to 9200. Its specific gravity varies from 1.3 to 1.8. When anthracite is heated with bituminous coal and pitch, about 80 per cent of coke is obtained. Anthracite ignites with difficulty, and when burning gives off but little flame and no smoke, but produces great heat. It breaks with a conchoidal fracture, and has a massive structure. Anthracite is found in South Wales round Swansea, and in Pennsylvania.

ANALYSIS OF WELSH ANTHRACITE.

Carbon.	Hydrogen.	Oxygen, Nitrogen, and Sulphur.	Ash.
91.29	2.33	4.80	1.58

Charcoal. Charcoal is the amorphous form of carbon obtained by heating wood in a *limited* supply of air. Although purer than coke it contains small quantities of alkalies, besides some oxygen and hydrogen gas.

Good charcoal should not soil the fingers, and should be hard, black, and sonorous. It preserves the form and structure of the wood from which it is prepared, and when ignited at one end will burn through to the other. Peat-charcoal retains the forms of the lumps of peat from which it was prepared, and when it contains but little ash is porous and friable, becoming harder and denser as the proportion of ash increases. Charcoal, especially animal charcoal, possesses in a remarkable degree the power of absorbing gases within its pores, and of extracting the colouring matter from solutions.

Various Modes of Charcoal-burning. The wood employed for charcoal-burning should be mature, neither too new nor too old, and should be cut when most free from sap. The wood must be stripped of bark and kept for some months before it is carbonized.

Wood is converted into charcoal in three ways:—

- (1) In piles, partially exposed to the air.
- (2) In closed chambers.
- (3) In closed retorts.

If prepared at a temperature of 350° to 400° C. the charcoal is hard and black; at a higher temperature it becomes brown in colour, denser, and more tenacious.

Charcoal-burning in Piles or Stacks. The site on which the wood is to be burnt should be well sheltered from wind, level, dry, and within easy reach of water.

The ground which is to constitute the floor of the pile should slant inwards from the circumference to the

centre. Three stakes are driven vertically into the centre of the floor, and logs of wood are arranged radially around the stakes. The whole pile is covered with turf (the grassy side inwards). This turf is again covered over with clayey soil mixed with charcoal, holes being made at the bottom to permit the ingress of a certain amount of air (see fig. 10). Ignited brushwood is then thrown down the central channel formed by the three stakes to start the burning. As combustion proceeds the logs

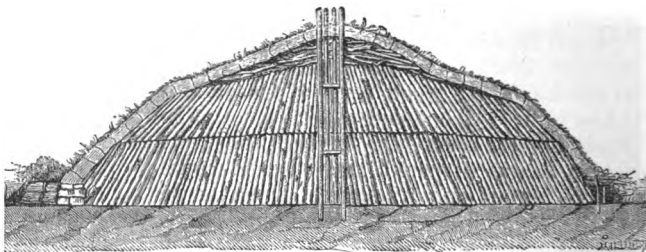


Fig. 10.—Making Charcoal from Wood. Conical Pile of Wood covered with Turf and Clay.

shrink, and an opening is made in the pile to allow the escape of water vapour. This is known as “sweating”. Holes are also made near the top of the pile to allow air (the amount of which is carefully regulated) to act upon the top layer; and, as the combustion proceeds downwards, the top holes are closed and other holes are opened in the sides and bottom of the stack. The progress of the combustion is judged by the character of the smoke which escapes from the top of the pile. The yield of charcoal varies from $\frac{1}{3}$ to $\frac{1}{2}$ the weight of the wood burnt. In some cases a circular basin is placed in the centre of the floor, and in this some of the by-products, such as wood-tar, &c., formed during the burning, are collected.

Wood is also frequently carbonized in rectangular heaps or stacks. A dry piece of ground is chosen having a slope of about 1 foot in 15 feet; and three parallel logs

are placed on this sloping bed, with their thickest ends at the upper end of the slope. Pieces of wood are then laid horizontally upon and across these logs, and are built up into the form of a stack, stakes being driven into the ground to support the stack at either end. A circular or rectangular channel passes through the stack to admit air. Combustion proceeds from one end of the stack to the other, the charcoal being removed as fast as it forms

CHAPTER VI.

FUEL (CONTINUED): COKE, COKING, AND COKE OVENS.

Coke. This form of carbon is obtained by subjecting coal to destructive distillation, whereby the volatile products are driven off and an impure more or less coherent mass of coke remains.

Every variety of coal yields coke; the caking, non-flaming, bituminous coals of the Cardiff district yielding the very best coke. This Welsh coal has the following composition:—

Carbon,	...	...	...	...	88 to 91 per cent.
Hydrogen,	...	...	...	...	5.5 to 4.5 „
Oxygen,	...	...	...	...	6.5 to 4.5 „

On distillation from 70 to 80 per cent of coke is obtained, with 18 to 26 per cent of volatile matter, of which 15 per cent is gaseous. Good coke should not soil the fingers, should not frit or break up, nor cohere on heating into a compact mass. When coke is produced by rapid heating, the volatile products are partly decomposed and the carbon resulting from them is deposited as silvery-looking scales on the coke. The higher the temperature to which coal is subjected, the greater is the yield of coke.

Coking is effected in piles or stacks, and also in kilns or in ovens, the first of these methods, however, being now rarely resorted to.

Properties of Coke. Coke is hygroscopic; when dry it will absorb $2\frac{1}{2}$ per cent of water from the air, and takes up from 20 to 50 per cent when plunged into water. Those cokes produced at a high temperature have a gray colour and metallic lustre, while those formed at a low temperature are black in colour and not lustrous. The coke or "breeze" used by blacksmiths is of this latter kind. Nearly all cokes contain sulphur, which is derived from the decomposition of the iron pyrites (FeS_2) in the coal. Coke requires a high temperature before it inflames, but gives out intense heat.

Some cokes (termed "hard coke") are dense and compact, others are porous and light.

Exposure to the weather renders coke soft and liable to crumble. For use in the blast-furnace coke should be dense and capable of resisting the action of the blast, and it should not readily yield to pressure.

The specific gravity of coke varies considerably, and is dependent upon the rapidity of the burning during the process of preparation of the coke; from 1.65 to 1.83 may be taken as the ordinary range of specific gravity of coke.

Approximate Composition of Coke. The chemical composition of coke depends upon the variety of coal employed, and upon the rapidity with which the heating of the coal is conducted.

The principal substances forming coke are carbon, ash, and sulphur. The following table gives the analysis of four different cokes:—

			1.	2.	3.	4.
Carbon,	...	...	94.08	92.87	97.60	92.70
Ash, ...	...	...	5.04	5.35	1.55	5.70
Sulphur,	...	...	0.88	1.78	0.85	1.60
			<hr/>	<hr/>	<hr/>	<hr/>
			100.00	100.00	100.00	100.00

The quantity of ash contained in the coke depends upon the ash contained in the coal, the sulphur also previously existing in the coal as a sulphide or a sulphate.

General Principles concerning the Preparation of Coke. The usual method of manufacturing coke is both crude and wasteful, although there have been many attempts to introduce new and improved methods. The main object of coke-makers is to produce a dense, compact coke in large lumps. This is effected by burning large quantities of coal stacked to a sufficient height to ensure long upright masses of coke in the oven at the end of the operation.

Coking must be effected at a high temperature in order that the products of distillation, ascending from the lower layers of coal, shall be decomposed and caused to deposit their carbon upon the coke already formed, thus increasing the total weight of coke.

Coking in Circular Piles. This method is rarely if ever now employed. A conical chimney built of fire-bricks and from 3 to 4 feet high is erected. This chimney has lateral apertures at different levels. Coal is arranged around the chimney, the heavier pieces being placed nearest the chimney, and the smaller pieces towards the outside, a rounded heap being thus formed. The whole is then covered with cinders and small coal. Channels pass through the bottom of the heap to the chimney to admit air. Burning coal is thrown down the chimney, the combustion of the pile then commencing at the centre, and gradually extending to the circumference.

Coking in Long Piles or Ridges. Coking in long piles is often substituted for the original round heaps. Sometimes the ridges are made 200 feet in length and about 2 feet high, the larger pieces of coal being placed at the bottom, and the smaller pieces at the top. A channel to admit air is left running the entire length of the pile; no covering to the pile is employed. The coal is ignited in more than a hundred distinct spots, and as soon as the thick smoke and flames cease at any one part the progress of the combustion at that point is stopped by covering the spot with powdered coal-dust. This is repeated until the whole of the ridge is covered, and the coke is then left for two or three days to cool.

Coking in large Open Rectangular Kilns. The process of coking in open kilns is often very successful if conducted in a proper manner.

The kilns are constructed of fire-clay bricks, and consist of two parallel walls, A, A, 40 to 60 feet in length, 5 feet high, and about 8 feet apart (see fig. 11). Air-channels or holes, B, B, are left in the brickwork at certain intervals. Each end of the kiln is partly bricked up, leaving an opening for the introduction of the coal. Vertical flues, C, C, are placed at the sides of the kiln so

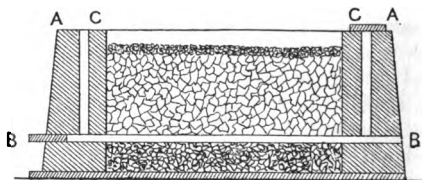


Fig. 11.—Coking in Rectangular Kilns.

that the draught of air may be increased if necessary. The coal is placed in the kiln, well stamped down, and moistened with water; long pieces of wood, 4 inches thick, are laid on the coal transversely, the ends of each piece of wood being opposite an air-channel. The kiln is then filled to the level of the outer walls, and covered with ashes and clay to exclude air. The wood is ignited through the air-channels, and the coal left to burn for ten or twelve days.

Each kiln holds from 200 to 300 tons of coal, and the loss of coke does not exceed 20 to 25 per cent.

Coke Ovens. The simplest form of coke oven is that called the "Bee-hive". From many coals a good variety of coke is obtained by this oven, but it is not economical. The coal is charged through a hole in the roof, and is caused to burn downwards from top to bottom. Air is sometimes admitted to aid combustion, but in the best forms of coke ovens the admission of air must be avoided as much as possible.

The chief points to be fulfilled by a good coke oven are—

1. The prevention of the escape of heat.
2. The utilization of the waste heat so as to cause the process of coking to proceed equally in all directions.
3. The easy removal of the coke.

Cox's Coke Oven. This oven consists of a rectangular chamber lined with fire-brick and closed in front

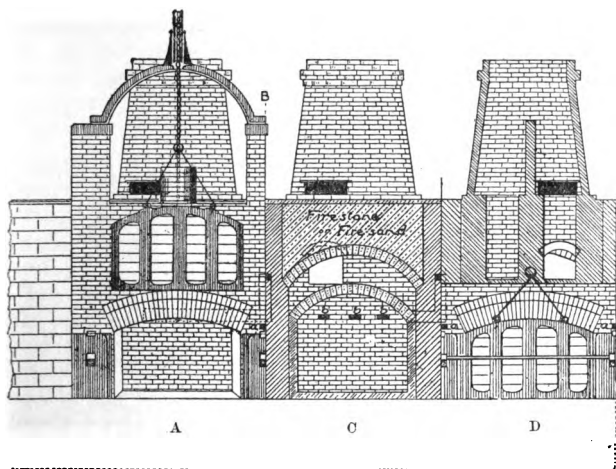


Fig. 12.—Cox's Coke Oven. *A*, Front view with door raised. *C*, Section of oven showing the double and hollow arched roof. *D*, Front view with door let down.

by an iron door also lined with fire-brick (see fig. 12 *D*). The oven has a double-arched roof *C*, forming a space through which the gaseous products must pass before reaching the chimney; within this space the waste gases give up a great part of their heat to the brickwork before finally passing away. A flue passes from either side of the door through the brickwork of each side of the oven and opens into the back of the oven, and the air traversing the flues becomes heated by the waste heat of the gases before entering the oven. The oven is

a little wider in front than behind, and the floor slopes down from the back towards the door, this construction enabling the coke to be more rapidly withdrawn.

Appolt's Coke Oven. This oven is built in the form of a rectangular shaft, A, about 13 feet high (see fig.

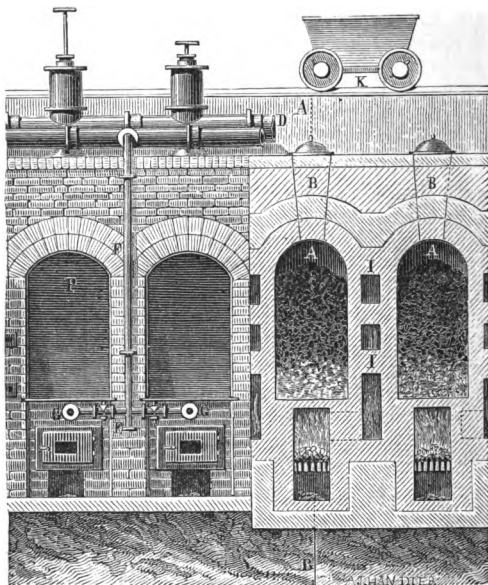


Fig. 13.—Appolt's Coke Oven. A, A, Coking chambers. B, B, Hoppers for charging in the coal. I, I, Lateral flues.

13). It tapers outwards from 44 by 13 inches at the top to 48 by 18 inches at the base, so as to allow the coke to be easily drawn out. Eighteen such vertical shafts or retorts are built side by side, each retort being surrounded by an air-space or flue, I, I, eight to ten inches wide.

Each retort has a cast-iron door at the bottom, opening into an arched vault below, into which the coke falls when the door is opened. The air-flues surrounding

each retort are connected to one another, and also open into the vertical retorts. The gaseous products of combustion from the coal escape into the air-flues, and there meeting with air are burnt, and produce sufficient heat to convert the remainder of the coal into coke. Each retort is charged with coal through the hopper B at the top, and the operation of coking is completed in about twenty-four hours.

Coppée's Coke Oven. The following advantages are claimed for this oven:—

1st. That nearly the whole of the total quantity of carbon present in the coal is retained as coke.

2nd. That the heat of the waste gases given off during the operation of coking is utilized by means of flues.

3rd. The by-products may be recovered.

Only finely-divided coal is coked in this form of oven.

This oven, like the Appolt oven, is heated by the combustion of the gaseous products from the coal in lateral flues on either side of each vertical retort (see fig. 14).

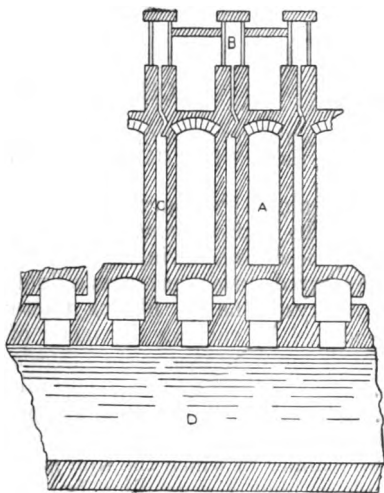


Fig. 14.—Section through Coppée's Coke Oven.

A, Chamber into which the coal which is to be converted into coke is placed. B and C, Flues along which the burning waste products pass to the bottom flue D.

SECTION II.

IRON AND STEEL.

CHAPTER VII.

IRON AND ITS PRINCIPAL PROPERTIES—COMBINATION OF IRON WITH CARBON—FORMATION OF STEEL.

Physical Properties of Iron. *Iron*, symbol *Fe* (from the Latin *Ferrum*, iron). This metal crystallizes in the cubic system: owing to its great ductility and tenacity a fractured surface presents a finely granular appearance.

A crystalline or fibrous fracture may, however, be produced by varying the mode of working the metal. Continued cold hammering causes iron to become hard and brittle, owing to the crystalline structure thus produced in the metal. If hammered hot, the iron becomes fibrous. The nature of the fracture also depends upon the manner in which the iron is broken; if broken by a sudden blow a crystalline fracture results; but if the same specimen of iron is broken by a series of gradually-increasing forces a fibrous fracture is produced.

Iron is opaque; it possesses a metallic lustre, and a grayish-white to black colour. Its specific gravity is 7·8; the density of the metal is, however, increased by compression at a high temperature; in wire-drawing the density of iron diminishes. Its melting point is 1600° C. Iron is a strongly magnetic substance, and may be readily magnetized by bringing it near to a magnet, or by inserting the iron into a coil of copper wire through which a current of electricity is passing. On removing the magnet or arresting the electric current, the iron reverts to its former neutral condition. Iron is a good conductor of heat and of electricity, its conductivity for heat being 11·9; silver, the most perfect conductor of heat

known, being taken as 100. The electrical resistance of iron is 5·8 times that of pure copper. At a white heat iron becomes softened and pasty, so that two pieces of the metal may be welded or joined together by hammering. Iron is the most tenacious of all known pure metals, and is the hardest of all those which are ductile and malleable. By intense cold the tenacity of iron is increased; thus Prof. Dewar finds that when iron is immersed in liquid oxygen (whose temperature is -180°C.) its tenacity is *doubled*. Iron occludes (or absorbs) about three times its volume of hydrogen gas. The presence of even minute quantities of foreign substances influences the character of iron, and it is a difficult matter to obtain a large mass of the pure metal. If pure hydrogen is passed over pure oxide of iron and the temperature raised, a reduction of the oxide ensues and chemically pure iron is formed.

Nature and Physical Properties of Steel.

Steel is a chemical compound of iron and carbon, which is capable of being hardened when subjected to suitable treatment. The amount of carbon combined with the iron varies in different kinds of steel. In "hardened steel" the carbon seems to be in a different state of combination to that in "soft steel". Thus "hardened steel" completely dissolves in dilute hydrochloric acid, but "soft steel" treated in the same way leaves a residue of undissolved carbon. The carbon in steel is but loosely held in combination with the iron, and may be got rid of by exposing the steel to a high temperature.

Steel has a bluish-gray colour, becoming white after hardening. It may be hardened by heating it to a high temperature and then plunging it into cold water. On hardening, the volume of the steel is increased by $\frac{1}{48}$ th of its volume. Steel may also be hardened by subjecting it to great pressure. Manganese, like carbon, has the power of hardening steel; but manganese steel is more brittle, and a little less elastic than carbon steel. Phosphorus and silicon also harden steel, whilst the presence of sulphur impairs the welding properties of steel.

The amount of carbon in steel varies from 0.15 to 1.8 per cent. "Ingot" or "extra soft steel" is made from very pure iron ores free from sulphur and phosphorus. It may be made by the Siemens - Martin process, but is difficult to make by the Bessemer process. It contains about 0.3 per cent of carbon.

This variety of steel is capable of being easily welded, and is therefore very useful for boiler plates.

"Very soft steels" contain from 0.25 to 0.35 per cent of carbon, steel containing the latter amount being especially useful for railway tyres.

"Ordinary soft steels" are easily modified by successive annealings and hardenings. They contain about 0.5 per cent of manganese and 0.3 per cent of carbon. This variety of steel may be made either by the Siemens-Martin or the Bessemer process, and is especially useful for railway springs, couplings, &c., owing to its high elasticity.

"Hard steels" are used for "dies" and for rails. They often contain 0.5 per cent of manganese, and from 0.5 to 0.8 per cent of carbon.

"Very hard steels" comprise all steels used for very hard rails and for ordinary steel tools. They nearly all contain manganese, sometimes as much as 1.5 per cent, together with 0.5 per cent of carbon. This kind of steel is also used for the facings of armour plates.

"Exceptionally hard steel." This variety is only used for certain tools, and is highly carburized. It is usually made in crucibles, and may contain tungsten and chromium as well as carbon.

Steel has a greater tenacity than any other metal. Its melting point lies between that of cast-iron and that of wrought-iron.

Welding as a Process. Welding is the name of the process by which two pieces of metal are united by simply hammering them together when heated.

This process is possible because of the property which wrought-iron possesses when raised to a white heat of uniting intimately under the hammer with a second

piece of heated iron without any appearance of a junction. The white-hot iron is sprinkled over with sand before the hammering takes place. This sand combines with the layer of iron oxide which is formed on the surface of the hot metal, and produces a liquid (iron silicate, which may be likened to a slag), which is then squeezed out by the hammering. Two perfectly clean surfaces of metallic iron are thus brought into contact, and on this fact the efficacy of the welding really depends.

“Burnt Iron.” When wrought-iron has been subjected for some time to a very high temperature but slightly lower than its melting point, a highly crystalline structure is produced; and this renders the iron extremely brittle and useless. If struck with a hammer the metal then breaks into fragments with bright shining faces. The fact is, that some of the iron becomes converted by the strong heat into the black oxide of iron, Fe_3O_4 , and this (together with the crystalline structure) renders the iron friable and brittle; it is then termed “burnt iron”.

Iron Scale, or Hammer Slag. When a “bloom” of iron is squeezed or hammered, a kind of slag is pressed out which is rich in oxide of iron, technically called “scale”. This “scale” or “hammer slag” is employed for making the working bottoms of puddling furnaces.

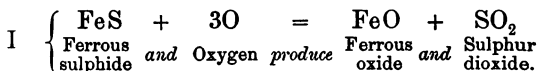
Preservation of Iron from Rust. When iron is exposed to moist air containing carbon dioxide, chemical reactions occur by which iron carbonate is formed; and this becoming oxidized, parts with its carbon dioxide again and is converted into the red iron oxide, Fe_2O_3 . This oxidation of the iron is continued until the whole of the metal is changed into ferric oxide, Fe_2O_3 , which, as it is produced, combines with the moisture present in the air to form hydrated ferric oxide, $\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$.

To prevent this oxidizing action of moist air the iron is usually coated with some material upon which oxygen has little or no action. A layer of paint, or of tin as in “tin-plates”, or an alloy of tin and lead as in “terne plates”, is often employed. Iron plates are also often

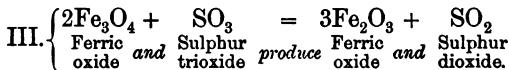
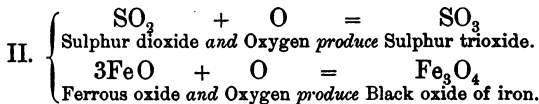
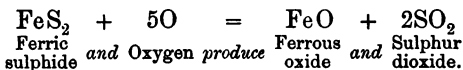
coated with zinc, and are then termed "galvanized iron".

In Prof. Barff's process iron is preserved from rusting by raising the metal to a red-heat, and then directing a jet of superheated steam upon it. A coating of the black oxide of iron, Fe_3O_4 , is formed, which effectually protects the iron beneath it from the action of oxidizing agents.

Sulphides of Iron roasted with Access of Air. When sulphides of iron (FeS , ferrous sulphide; or FeS_2 , ferric sulphide) are heated in contact with air, chemical combination ensues between the iron, the sulphur, and oxygen (from the air), whereby sulphur dioxide, sulphur trioxide, and ferric oxide are produced. The reactions are rather complex, a considerable number of intermediate compounds being formed. The following equations represent the final result of the chemical changes which take place and the products which are formed:—



With ferric sulphide the following reaction takes place:—



Iron and Phosphorus. The two elements known as "iron" and as "phosphorus" unite to form a phosphide of iron, which probably has the formula Fe_{12}P . If magnetite is reduced in the presence of calcium phos-

phate the phosphorus is liberated, and unites with the iron. Very few examples of pig-iron are wholly free from phosphorus. If the proportion of phosphorus exceeds .5 per cent the iron is rendered "cold-short"; .3 per cent hardens bar-iron; while the presence of 1 per cent renders the iron weak and brittle, imparting a crystalline structure, and increasing the fusibility and fluidity of the metal. When present in very small quantities phosphorus improves iron for castings, increasing the fluidity of the metal, and thus enabling the iron to fuse tranquilly, and to flow readily.

Malleable iron may contain as much as 0.8 per cent of phosphorus. The less carbon there is present the more phosphorus can be contained without detriment to the iron. The average proportions of phosphorus in the best English pig-iron are shown in the following table:—

Varieties of Pig-iron.	Phosphorus.
Staffordshire mine	$\frac{1}{2}$ to 1 per cent.
Scotch pig	1 per cent.
Cleveland pig	$1\frac{1}{2}$ "
Northampton pig	$1\frac{1}{2}$ "
Staffordshire cinder-pig	$2\frac{1}{2}$ "

Reduction of Silicate of Iron by Carbon. On heating carbon with silicate of iron in a crucible, reduction of the silicate takes place with the formation of metallic iron—generally in the form of white pig-iron—together with a little highly siliceous slag.



Iron and Carbon. Carbon combines chemically with iron in various proportions, forming the many varieties of pig-iron and steel. The maximum quantity of carbon with which iron can normally combine is about $4\frac{1}{2}$ per cent; but the presence of manganese enables iron to combine with a still larger proportion of carbon: thus

when 4 per cent of manganese is present in the iron, $5\frac{1}{2}$ per cent of carbon can be retained by the iron.

The carbon in iron occurs in at least four forms, two of which are soluble in dilute hydrochloric acid, and two which are not soluble. Combination of the two elements takes place when iron is heated in contact with free carbon, or with gaseous fuel such as carbonic oxide and the hydrocarbons; or when iron is brought into immediate contact with incandescent solid carbonaceous fuel. In the cementation process iron is heated for a considerable time in contact with solid carbon; the two elements then combine with, as a result, the production of steel.

In "Darby's process" molten wrought-iron is allowed to run into a "mixer", into which at the same time the requisite quantity of carbon necessary to form steel is introduced. Carbon hardens iron, and lowers its melting point.

The discovery of the importance of carbon in iron was made by a Swede named Bergmann in the year 1781.

Modes of Effecting the Combination of Carbon with Iron. Carbon may be caused to combine with iron in a variety of ways. About two centuries ago both Clouet and Pepys heated pieces of wrought-iron in contact with diamond dust, and obtained steel due to the combination of the two elements.

If wrought-iron is melted, and carbon in the form of charcoal or coke is then added to it, a definite shade of steel is produced.

A better way of adding carbon to iron, is to put a variety of pig-iron termed *spiegeleisen* into the molten iron; *spiegeleisen* contains a considerable quantity of manganese and of carbon, and combination of the iron with the carbon is much more readily effected if manganese is also present.

On heating solid wrought-iron for a considerable time in contact with carbon, the iron—without passing into the liquid state—combines with the carbon, and is converted into steel. This is the basis of the "cementation process" for the production of steel.

Manufacture of Steel by Cementation. In the cementation process, wrought-iron is converted into steel by inducing it to take up carbon from a mass of the latter element in which the iron is embedded, when the whole is heated to a high temperature.

In this cementation process only the best Swedish bar-iron is used, "blister" steel being the first product; this is afterwards melted (so that the highly carburized iron on the exterior of each bar, and that hardly affected in the interior, shall become uniformly mixed) and converted into "cast" and "shear" steel.

The bars of wrought-iron are placed in chests of siliceous stone and covered with a cement of powdered charcoal; on heating the whole for about 18 days the iron (without melting) absorbs carbon, and "blister steel" is the result. This is termed "carburizing" cementation.

By an inverse process, the decarburization of cast-iron is effected by heating it to redness with oxide of iron, hematite being usually the oxide employed; the cast-iron then becomes malleable, owing to the burning out of most of its carbon. This is an example of "oxidizing" cementation.

Agricola (died 1555) was the first to describe the manufacture of steel by heating wrought-iron with pig-iron; the pig-iron then losing about 1 per cent of carbon, and the wrought-iron gaining $\cdot 4$ per cent of carbon. The two forms of iron are thereby simultaneously converted into steel.

Amount of Carbon in Iron. Malleable iron, steel, and pig-iron differ considerably in their properties, the differences observed being mainly due to the variation in the percentage of carbon present in the different varieties.

Malleable iron may contain up to $\cdot 15$ per cent of carbon without its malleability being affected. In *steel* the carbon varies from $0\cdot 15$ up to $1\cdot 8$ per cent, the "hard steels" containing a larger percentage of carbon than the "soft steels". When more than $1\cdot 8$ per cent of carbon is present we have *cast-iron*. In *molten pig-iron* the carbon is chiefly present in solution, though partly also in com-

ination. A high temperature and slow solidification are conditions favourable to the separation of carbon from iron, in the form of graphitic scales (called "kish"), which are visible when the mass is cooled. Rapid solidification of the pig-iron is unfavourable to the separating out of the carbon, and it therefore remains combined with the iron. It will thus be seen that carbon exists in iron in two states, the free and the combined. In "gray" pig-iron the carbon exists principally in the graphitic or uncombined state. In "white" pig-iron the carbon is principally in the combined condition. When the proportions of combined and uncombined carbon are equal, a freshly fractured surface of the iron has a "pied" or speckled appearance, the gray graphitic plates being enclosed in a meshwork of white lines; it is then termed "mottled iron".

"White" pig-iron can be changed into "gray" by melting and allowing the molten mass to cool slowly, when graphite or "kish" separates out. The addition of aluminium or of silicon has the same effect. If "gray" iron is melted and then suddenly cooled, it is converted into the white variety. This is the principle of "chill-casting" employed in the manufacture of shrapnel shells. The quantity of carbon which iron is able to take up increases as the temperature of the metal increases.

"Red-shortness." When iron is unworkable at a red-heat it is said to be "hot-short" or "red-short". This is due to the presence of certain impurities, such as arsenic and sulphur.

"Cold-shortness." The presence of silicon or of phosphorus renders iron unworkable when cold, the metal cracking and presenting a crystalline fracture. It is then said to be "cold-short". Some varieties of iron are both red- and cold-short.

CHAPTER VIII.

THE ORES OF IRON: PRIMITIVE PROCESSES FOR THE EXTRACTION OF IRON FROM ITS ORES.

The Ores of Iron: their Physical Properties and Chemical Composition.—(1) Native Iron.

Metallic iron is rarely met with in nature; certain basaltic rocks in Greenland contain particles and even large masses of nearly pure iron. And in New Zealand iron alloyed with nickel has been discovered, forming the mineral named *Awaruite*. Meteorites containing iron alloyed with nickel, cobalt, chromium, and other elements have been found in different parts of the world. Interspersed throughout the mass of nickeliferous iron, which constitutes the greater part of these visitors from space, we find certain crystalline minerals, as sulphides of iron, silicate of magnesia and iron, and phosphides of iron and nickel. The surfaces of the meteorites are covered naturally with a fine glaze or layer of melted glassy matter, which protects the iron within from rusting.

Although iron occurs in a great variety of minerals in chemical combination with other elements, it is almost solely extracted from its oxides and its carbonates.

(2) Magnetite, Magnetic Iron Ore, or Black Iron Oxide. This mineral when pure contains 72·4 per cent of iron; and each molecule consists of three atoms of iron combined with four atoms of oxygen, Fe_3O_4 . It crystallizes in the cubic system. This oxide of iron is black in colour, giving a black streak when drawn across a plate of unglazed porcelain, and has a metallic lustre. It is a strongly magnetic substance, and is occasionally found naturally magnetized, when it is known as "lode-stone". Its specific gravity varies from 5 to 5·5. This ore of iron is sometimes found crystalline; but more usually in compact, granular, or earthy masses. It occurs in serpentine, in hornblende, and in chlorite schists, and also in certain crystalline limestones. The purest magnetic iron ores are those of Persberg and Dannemora, in

Sweden; the magnetite of Gelivará in Lapland contains much phosphorus.

(3) **Franklinite.** This ore contains about 45·53 per cent of iron. It varies considerably in composition, containing the oxides of iron, zinc, and manganese, as represented by the following formula: $(\text{FeZnMn})\text{O} + (\text{Fe}_2\text{Mn}_2)\text{O}_3$. Its specific gravity is 5·1; and like magnetite it crystallizes in the cubic system; but it is also found massive and compact. It is black in colour, and leaves a reddish-brown streak. Franklinite is chiefly found at Franklin and Stirling, New Jersey, U.S.A., where the zinc is first extracted, and the remaining compound of iron and manganese smelted as an iron ore.

(4) **Chromite.** An oxide of chromium, iron, magnesium, and aluminium, $(\text{MgFe})\text{O} + (\text{Cr}_2\text{Al}_2)\text{O}_3$, and containing about 22 per cent of iron. It crystallizes in the cubic system; is brownish-black in colour; and leaves a brown streak. Specific gravity = 4·4. This ore is found at Dun Mountain, New Zealand, and in the Bare Hills, near Baltimore, U.S.A.

(5) **Hematite or Red Iron Oxide.** Each molecule of this important ore of iron consists of two atoms of iron combined with three atoms of oxygen, Fe_2O_3 . When pure, which is very rarely the case, it contains 70 per cent of iron. It crystallizes in the hexagonal system; and also forms kidney-shaped and fibrous masses. The specific gravity of the crystalline forms is 5·3; being as low as 4·5 in the earthy varieties. Its colour varies from bluish iron-black in crystals, to bronze-red and vermilion in the earthy or amorphous forms. It leaves a red streak upon an unglazed porcelain plate.

The brilliant, well-crystallized forms of hematite are termed *Specular iron ore*, and these are found at Elba, Brazil, and St. Gothard. Micaceous iron ore, a scaly compact variety, occurs in South Devon and in Brazil. Specular schist or slaty hematite forms beds of great thickness at Marquette, Lake Superior. Kidney iron ore is very abundant in Lancashire and Cumberland, occurring as large irregular masses in the Mountain Limestone of

those counties. Puddler's ore is a soft greasy form of hematite from Cleveland and Furness, which is employed for lining puddling furnaces.

(6) **Ilmenite or Titaniferous Iron Ore.** The composition of this ore varies; it contains iron, magnesium, titanium, and oxygen, as represented in the following formula— $\text{FeOTiO}_2 \cdot \text{MgOTiO}_2$. It contains about 20·6 per cent of iron. It crystallizes in the hexagonal system; and also occurs massive and granular. Its specific gravity varies from 4·30 to 5·21. It is black or dark-gray in colour, and leaves a black streak. It is sometimes magnetic. Titaniferous iron ores are usually free from phosphorus and sulphur; but are very refractory. The chief localities are the Labrador beaches (where it occurs in the sand), and Arendal, in Norway.

(7) **Turgite.** A hydrated oxide of iron, $2\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$. It contains about 69 per cent of iron. It forms massive and fibrous lumps of a reddish-brown colour, and leaves a bright red streak. Its specific gravity is 3·74. The chief locality for this ore is Bogoslowsk, in the Urals.

(8) **Göthite.** Also a hydrated oxide of iron, $\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$; containing 63 per cent of iron. It crystallizes in the rhombic system. It has a yellowish-brown to black colour, and leaves a reddish-brown streak. Specific gravity = 3·8 to 4·4. The chief locality is Cornwall.

(9) **Limonite or Brown Iron Ore.** A hydrated oxide of iron having the formula $2\text{Fe}_2\text{O}_3 \cdot 6\text{H}_2\text{O}$; and yielding 60 per cent of metallic iron. Forms fibrous, granular, and earthy masses. Brown to nearly black in colour; leaving a yellowish-brown streak. Its specific gravity varies from 3·6 to 4·4. The "Bean ore" of Germany, "Lake ore" of Sweden, together with "Yellow Ochre", are but varieties of limonite containing clay, sand, and phosphoric acid.

(10) **Chalybite, Siderite, or Spathic Iron Ore.** This is a carbonate of iron, FeCO_3 , and contains 48·2 per cent of iron. It crystallizes in the hexagonal system. Yellowish-gray to brown in colour, and has a specific gravity of 3·7. This ore rarely occurs pure, generally containing

some manganese and calcium, and is often found mixed with clay, quartz, and carbonaceous matter.

The varieties of spathic iron ore rich in manganese are smelted for the production of spiegeleisen and ferro-manganese.

(11) **Clay Ironstone** and "**Gubbin**" are nodular masses of carbonate of iron containing an admixture of clay and carbonaceous matter. They are very free from sulphur and phosphorus.

(12) **Black-band Ironstone** is a compact iron carbonate, containing sufficient carbonaceous matter to burn when ignited, so that the ore can be calcined without the addition of fuel. The Brendon Hills in Somersetshire, the Cleveland district, and Northampton are the chief localities for stratified spathic iron ores. Clay ironstone also occurs in South Staffordshire and Yorkshire. The central coal-fields of Scotland yield black-band ironstone.

(13) **Iron Pyrites**. A sulphide of iron, FeS_2 . It contains 46.7 per cent of iron, and 53.3 per cent of sulphur. Crystallizes in the cubic system. Usually brass-yellow to white in colour; leaves a black streak. Its specific gravity varies from 4.9 to 5.2.

This mineral, although very abundant in Britain and several other countries, is only used as a source of iron after the sulphur has been nearly all driven off in the manufacture of sulphuric acid. The residue consists mainly of oxide of iron, and is termed "blue billy".

Classification and Metallurgical Value of the Ores of Iron. Iron ores may be classified in many ways. 1. Simple ores, as *magnetite*; their value depending upon the nature and amount of gangue associated with them. The gangue may be metallic, earthy, siliceous, or basic.

2. Ores are also frequently divided into refractory and fusible. Or they may be classified according to the amount of metallic iron contained in them; iron ores are not considered rich if they do not contain at least 50 per cent of the metal.

3. Ores vary considerably as to the readiness with

TABLE OF IRON ORES.

	OXIDES.			CARBONATES.	
	Magnetite	Hematite.	Limonte.	Spathic Ore.	Clay Ironstone.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Ferric oxide,	30-70	60-95	50-90	0-5	0-10
Ferrous oxide,	15-55	0-5	—	20-60	30-45
Manganese oxide,	0-1	0-2	0-2	1-25	0-2
Magnesia,	0-2	0-1	0-2	0-10	1-10
Alumina,	0-10	0-5	1-10	0-5	1-10
Lime,	0-5	0-3	0-5	0-25	1-10
Silica,	0-25	1-25	1-30	0-5	2-25
Carbon dioxide, ..	0-5	0-2	0-5	35-40	20-35
Phosphorus pent-oxide,	0-2	0-3	0-3	traces	0-3
Sulphur,	0-2	0-1	0-1	traces	0-2
Water,	0-5	0-5	5-20	0-5	0-4

which they are reduced to the metallic state. Silicates, oxides containing silica, and titaniferous iron ores are difficult to smelt, whilst porous oxides are comparatively easy.

4. The size of the fragments of ore is often of great importance.

Iron ores containing a good percentage of manganese (as *Franklinite*) are smelted for the production of spiegel-eisen and ferro-manganese.

Chromite yields iron and chromium alloys, from which a highly tenacious steel is produced. *Ilmenite* containing more than 8 per cent of titanitic acid is useless as an ore of iron; but may be used as a fettling or lining for puddling furnaces. Iron ores should be as free as possible from silica; and also from minerals containing sulphur and phosphorus.

Direct Extraction of Iron in the Malleable State from the Ore. In the earliest times, the iron ores were simply mixed with fuel and heated to redness, and the reduced metallic mass worked by hammering. By "direct extraction" we understand those methods in which cast-iron is produced at once by direct smelting;

the cast-iron being then immediately changed into wrought-iron or steel by decarburization. The iron is thus extracted from the ore in one operation. The Catalan, Chenot, Blair's, and Siemens' processes, are methods in which workable iron is produced from iron ores in one operation (see scheme below, fig. 15).

Primitive Appliances for Working Iron Ores.

The earliest forges were always situated on the side of a hill, the hearth being merely a hole in the earth. A

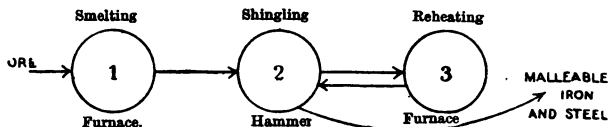


Fig. 15.—Scheme for the production of Iron and Steel by direct processes.

natural draught of air was first used, this being in later times replaced first by single and then by double acting bellows.

The first fuel used was charcoal, only easily reducible ores being smelted. The iron was thus obtained as a spongy mass, the loss of metal being very great.

In Finland at the present day, bog-iron ores are smelted in a simple open furnace; the iron so produced contains much phosphorus, but is very malleable.

Catalan Process for the Direct Smelting of Iron Ores. The Catalan forge still lingers in the south of France, in Spain, and among the Austrian hills. It consists of a forge and a blowing machine called a "Trompe".

Limonite, hematite, and spathic ores are the forms of iron ore usually smelted, the first of these being preferred. The forge consists of a shallow, oval cavity, wider at the top than at the bottom, and slightly coned upwards towards the working side. The bottom is made of refractory stone, the forestone being of wrought-iron. A twyer, T, enters through the back of the forge and is inclined at an angle of 30 degrees 40 minutes, and is 2 feet 9 inches from the bottom of the cavity (see fig. 16).

About 10 cwts. of ore are crushed to powder and sifted to get rid of the lumps. The hearth is used while still red-hot from the previous charge, a mass of incandescent charcoal being left at the bottom; fresh charcoal is then added until the lower end of the twyer is nearly reached. A plate of iron is now introduced, dividing the cavity into two parts; more charcoal is placed on the twyer side of this, and ore on the other side. The ore is heaped up

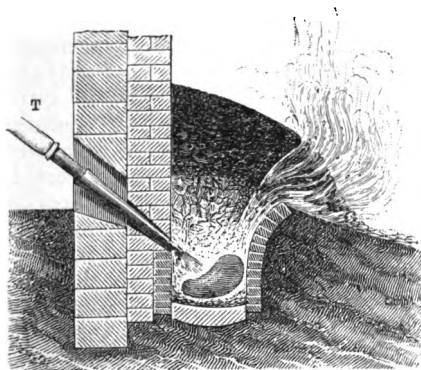


Fig. 16.—Catalan Forge. *r*, Twyer.

until it forms a low mound outside the cavity. The iron plate is now withdrawn and the blast turned on. Carbonic oxide is at once formed, which penetrates the mass of ore, reducing it to metallic iron as soon as the temperature is high enough. The first product to be formed is ferrous oxide, FeO , and this combines with the silica present, producing a fluid slag, having the composition $2\text{FeO} \cdot \text{SiO}_2$. A considerable amount of slag is accordingly formed at the expense of the iron. The nature of the iron obtained varies very considerably; a little cast-iron is occasionally produced, but only a small part of the metal is fused. The amount of carbon retained in the iron is dependent upon the degree of oxidation, on the inclination of the twyer, and also upon the length

of time the iron is allowed to remain in contact with the fluid slag of basic silicate of iron.

The Catalan process resembles the puddling process in the chemical reactions which take place. In both processes the action is oxidizing, the formation of a basic ferrous silicate being a feature common to the two processes.

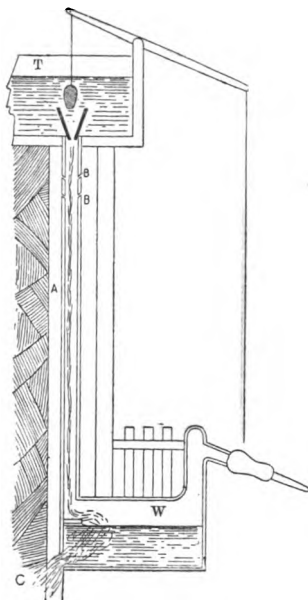


Fig. 17.—Trompe, or Blowing Machine. W, Wind-chest. T, Tank. A, Wooden tube. B, B, Lateral orifices. C, Outlet for water.

Trompe, or Blowing Machine. The “Trompe”, or machine used for supplying the blast to the Catalan forge, was introduced in the 17th century. It consists of a wooden tube, A, 12 to 15 feet high, with lateral orifices, B, B, slanting downwards into the tube from the outside. The top of the wooden tube can be closed at will by a plug. The upper end of the tube passes into a tank, T, filled with water and open to the air; the lower end is connected with the wind-chest, W, in which air accumulates; both the tank and the wind-chest hold about 10 tons of water (see fig. 17). On lifting up the plug, water falls

down the tube with accelerated velocity, air being thereby dragged in through the lateral orifices, and passing along with the water into the wind-chest. The water falls upon a ledge in the wind-chest and flows away through a hole C in the bottom. The air passes as a strong current or “blast” through the twyer into the furnace; this blast of air is saturated with water vapour.

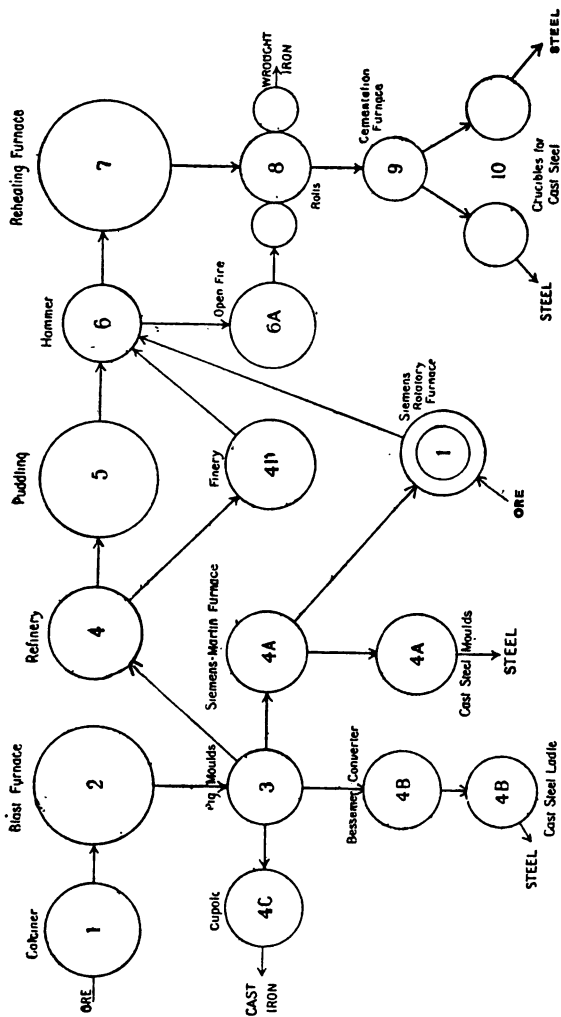


Fig. 18.—Scheme for production of Iron and Steel by indirect processes.

The action of the "Trompe" was first explained by Sprengel in 1865.

Indirect Extraction of Iron in the state of Cast-iron from the Ore. By the "indirect" extraction of iron from the ore, is understood first the preparation of pig or cast iron; and then the preparation of wrought-iron from this pig-iron by fining and puddling, or by inverse cementation.

Thus, in the indirect process, instead of obtaining workable iron in *one* operation, as in the Catalan and Siemens processes, the iron has to undergo a *series* of operations whereby its impurities are successively eliminated, and wrought or malleable iron is produced (see scheme above, fig. 18).

CHAPTER IX.

THE MODERN BLAST-FURNACE: ITS CONSTRUCTION AND ITS USES.

Calcination and Roasting of Iron Ores. As before mentioned the object of calcining and roasting metallic ores is to remove volatile products, and to render the ores spongy and porous.

In many countries spathic and clayey iron ores are simply roasted in heaps. The ore is heaped up on a paved floor, and a little coal or turf or faggots of wood is added for fuel. In Lanarkshire, these heaps are built from 3 feet to 12 feet high, requiring from 10 to 12 per cent of fuel.

It is more usual, however, to calcine the iron ores in some form of kiln or furnace. In these calcining furnaces the heat should not be so great as to produce either fusion or agglomeration of the ore.

One of the best forms of roasting furnace is that known as "Gjers", largely used for roasting the spathic ores of the Cleveland district. This furnace is about 30 feet high and 18 feet wide at the top, the diameter at the

"boshes" being about 20 feet, and at the base about 14 feet (see fig. 19). The body of the furnace is of fire-brick, encased in wrought-iron plates, and is supported by cast-iron pillars, P, P. In the centre of the base of the furnace is an iron cone, C, 8 feet in height, and of the same diameter at its base.

The calcined ore is discharged through openings, o, o, around the base of the furnace, being directed outwards by the iron cone. Such a furnace has a capacity of about 6000 cubic feet, three days being required for the roasting.

Vat-like furnaces are sometimes used, gaseous fuel being projected into them. In the "Dannemora" kiln, heat is supplied by introducing blast-furnace

gases through ten tubes, air being also admitted into the kiln to effect the combustion of these gases.

Description of the Modern Blast-furnace; foundation, hearth, twyer openings, twyers, tunnel head, bracing, blast main, and blast pipes. In England, blast-furnaces were first introduced about 1300 A.D. for smelting the iron ores found on the borders of Surrey and Sussex. In the sixteenth century, Queen Elizabeth placed several restrictions on iron smelting in Surrey and Sussex, owing to the nuisances created thereby, and to the destruction of the forests for the production of the charcoal required in the operation of smelting. In 1611, a patent was granted to utilize coal in blast-furnaces; but this early attempt was not successful. In 1735, Abraham Darby first applied coke to the blast-furnace.

The height of a blast-furnace depends on the nature of the fuel used and on the character of the ore to be smelted. Thus in the Cleveland district the furnaces

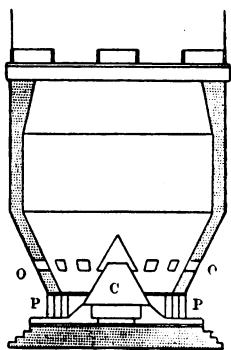


Fig. 19.—Giers Furnace. c, Cone. P, P, Pillars. o, o, Lateral openings.

are built high, as the ore found there is comparatively light in weight. In the older forms of blast-furnace there was above the charging gallery (round the top of the furnace) a slighter brickwork continuation of the internal cavity which was termed the *tunnel head*, in which door-holes were pierced (closed with movable iron doors) for the introduction of the charge of ore, fuel, &c.

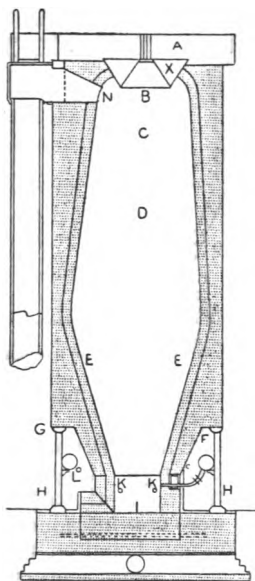


Fig. 20 — Blast-furnace. x, The cup.
B, Movable cone. N, Flue for waste
gases. E E, Boshes. K K, Tways.
L, Main blast. I, Hearth.

The modern blast-furnace is barrel-shaped or nearly cylindrical in form, and varies in height from 39 ft. to 75 ft. The diameter varies from 6 ft. to 28 ft.; but in the latter type of furnace there is a tendency for the gases to move up the sides of the furnace, thus leaving a central column of ore which is only incompletely acted upon (see fig. 20).

The widest part of the furnace (where the interior angle of the furnace changes) is called the "boshes", E, E; in some furnaces there are either no boshes at all or the change in curve is very slight.

The exterior casing of a blast-furnace is formed of wrought-iron plates riveted together.

Within these is built the casing of ordinary masonry; the interior of the furnace being lined with fire-brick. Between the fire-brick lining and the masonry is a layer of sand or powdered coke, which allows the fire-brick lining to expand and contract without disturbing the external masonry. The furnace is supported by a cast-iron ring resting on iron pillars; which in their turn rest upon a prepared foundation.

The foundation of the blast-furnace in the Middlesbrough district consists entirely (up to the ground-level) of brickwork resting on clay. Above this point a circular base is carried up to a height of 7 feet in solid brickwork, chiefly of fire-brick, with a stone curb all round on which the iron pillars supporting the body of the furnace rest (see fig. 21).

The hearth, or rectangular space, I, at the bottom of the furnace in which the molten iron collects is independent

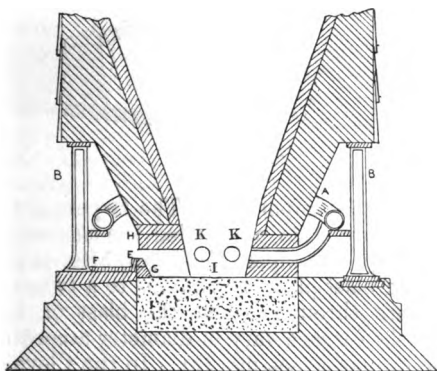


Fig. 21.—Blast-furnace. A, Main blast. B, Pillars supporting body of furnace. I, Hearth. K, Twyers. H, The dam. F, Iron dam-plate. G, Fore-hearth. E, Tymp-stone.

of the masonry of the body of the furnace. It is lined with a highly refractory non-corrosive material capable of withstanding the action of great heat and of the molten slags. The width of the hearth varies in different localities, being from 6 to 8 feet wide in Scotland; from 5 to 9 feet in Wales; and 8 feet wide in the Cleveland district.

Three sides of the hearth or crucible are occupied by the twyers, K, K; the fourth side being arranged for the tapping out of the molten iron and slag. Towards this side (known as the front or working side) the hearth is continued for a short distance, forming the fore-hearth (G, fig. 21), which is itself bounded in front by the dam-

stone, E. The arch covering the fore-hearth is termed the tump-arch, H. In many cases this fore-hearth is dispensed with altogether. The tap-hole through which the molten iron runs out of the furnace is a narrow slit passing through the base of the dam-stone, and is plugged during the smelting of the ore with a lump of clay.

The openings in the sides of the hearth within which the twyers are placed must not be too far apart, for the distance by which the twyers are separated from each



Fig. 22.—Twyers.

other is extremely important. The twyers are supplied with hot air by a wide pipe called the *blast main*, which divides into separate pipes (*blast-pipes*) after it enters the furnace; each blast-pipe carrying air to a twyer.

The twyers through which the blast of hot air is forced into the furnace vary in diameter according to the volume of the blast (see fig. 22). In the Cleveland furnaces there are from four to seven twyers to each furnace, each twyer having a diameter of 6 inches; this diameter being greater than usual owing to the great width and height of the furnaces used in that district. The average pressure of the blast of air at the twyer is from 4 to 5 lbs. per square inch. The twyers are placed from 3 feet to 3 feet 6 inches above the floor of the hearth. Each twyer consists of a wrought-iron coiled tube encased in the sides of a cast-iron tube. Water traverses the coiled tube, thus preventing the twyer from melting. In Lloyd's spray twyer, a spray of cold water is conveyed between the double sides of the nose of the twyer.

ACTION OF THE BLAST-FURNACE.

In a blast-furnace there are two streams or currents to be noticed: (1) an ascending current of hot gases; and (2) a descending solid stream of fuel, flux, and ore.

Heat is produced by the combustion of the fuel near the twyers, the temperature being very high where combustion occurs, and decreasing gradually towards the top of the furnace. The mixture of ore and fuel as it descends is slowly heated, and the ore is ultimately reduced to metallic iron by the chemical reactions which take place between it and the constituents of the heated ascending gaseous current.

The velocities of the two currents are, however, very different. The gas ascends rapidly, retarded of course to some extent by the descending current, at the rate of about 3 feet per second. The solid current of ore and fuel on the other hand descends with a velocity of only about 3 feet per hour.

The rate at which reduction of the ore takes place depends on (1) the purity, (2) the temperature, and (3) the velocity of the gaseous currents. The temperature and degree of velocity of the ascending current varies of course with the force of the blast.

The composition of the upward gaseous current depends on the relation of the air admitted to the amount of fuel and ore charged in; and its composition slowly changes as it rises from the twyers to the throat of the furnace. Near the twyers, carbonic oxide is the principal gas; and as this carbonic oxide rises higher in the furnace, it reduces the oxides of iron in the ore; being itself thereby converted into carbon dioxide. The carbon dioxide may pass out from the furnace as such; or it may combine with incandescent solid carbon (from the fuel) and thus revert to the state of carbonic oxide again.

The carbon in the fuel, &c., contained in the furnace may be burnt in two ways:—

(1) It may be actually burnt at the level of the tuyers by means of the oxygen in the air-blast; or—

(2) It may be burnt at a higher level by reducing the carbon dioxide.

As carbonic oxide is the active reducing agent in the blast-furnace, the greatest care must be taken to regulate the rates of the ascending and the descending currents; so that there shall be no undue combustion of carbon by carbon dioxide in a part of the furnace where it could do no good. Should the carbon dioxide combine with carbon higher up, as near the throat of the furnace, carbonic oxide would be formed, which in that position could be of no service as a reducing agent.

The relation of the carbonic oxide to the carbon dioxide in the gaseous current is modified by the velocity and temperature of the blast; and it also depends in part on the nature of the fuel used. For instance, charcoal favours the formation of carbonic oxide more than coke does; and coke more than anthracite.

It must be remembered that the iron-master has in reality only one class of compounds to deal with, namely, the oxides of iron; and that the reduction of these oxides to metallic iron in the blast-furnace is really effected by the agency of carbonic oxide. Now the reductive energy of carbonic oxide depends upon its purity and its temperature; while the purity of the reduced iron depends on the purity of the ore and fuel and the temperature of the furnace.

Hot Blast. The "blast" (or introduction of a current of air into a furnace), in anything like its present form, was first used at the Carron ironworks, and was there worked by water-power. When steam came into general use as a source of power, the blast came to be almost universally employed. In 1828 Neilson conceived the idea of *heating* the blast of air before admitting it into the furnace, and took out a patent for "The improved application of air to produce heat in stoves, furnaces, &c." At first the innovation was regarded with suspicion by iron-masters; but in 1869, of the 4,000,000 to 5,000,000

tons of pig-iron produced in the United Kingdom, only from 1000 to 2000 tons were produced by "cold blast".

The advantages of using a *hot blast* are obvious. Heat is thereby conveyed into the furnace; while if cold air is admitted its temperature has to be raised at the expense of the heat of the furnace. Less carbon is burnt, and less is required for the fusion and reduction of the ores; there is thus a saving of fuel when the hot blast is used. The yield of iron, too, is greater, and the iron itself is more uniform in composition. The interpenetration of the descending current of ore and the ascending current of gases is also regulated by the use of the hot blast. If the furnace works badly, a remedy is at once found by increasing the blast.

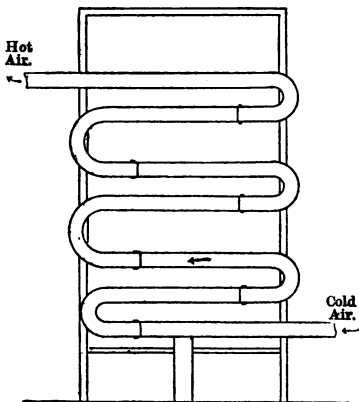


Fig. 23.—Syphon-pipe Stove for Heating Blast.

The chief disadvantage of the hot blast is that the oxides of silicon, calcium, magnesium, manganese, and aluminium are reduced as well as the oxide of iron.

These five elements (along with sulphur and phosphorus—whose oxides are easily reducible) then pass into and mingle or combine with the metallic iron.

Apparatus for Heating the Blast. The blast of air may be heated in two ways:—(a) by passing the current of air through cast-iron pipes, heated externally by a distinct or special fire; or (b) by causing the air to traverse fire-brick chambers, which have been previously heated by the hot waste gases from the blast-furnace.

Syphon-pipe for Production of Hot Blast. Cold air is caused to pass through syphon tubes or pipes

fastened end to end by sockets made tight with sand, a fire being lighted beneath to heat the cold air as it passes through the tubes (see fig. 23). The syphon-pipes, instead of being in a long row, are doubled on themselves, forming a round box-oven heated by a fire. Serpentine tubes were also at one time employed, these in some cases being fixed at the top of and being heated by the escaping flames of the blast-furnace.

The Gases of Iron-smelting Blast-furnaces. The composition of the gases of blast-furnaces depends upon the part of the furnace from which the gases are drawn. The gases form an ascending current, and were formerly allowed to escape into the air, but are now always conveyed away by pipes and their heat extracted from them. We have already stated that in blast-furnaces for iron-smelting the iron oxides are reduced by carbonic oxide, CO. If, therefore, the rapidity of the ascending current of hot gases be too great, only a partial reduction of the ore can take place, and a considerable amount of the iron will pass into the slag. If, however, the gaseous current be too slow, the carbonic oxide is rapidly converted into carbon dioxide at the expense of the blast, and thus the reducing gases are wasted.

COMPOSITION OF FURNACE GASES.

		Lowest percentage.		Highest percentage.
Nitrogen, ...	...	52	.....	70
Carbonic oxide, ...	...	22	.....	41
Carbon dioxide, ...	...	4	.....	22
Marsh gas, ...	...	0.1	.....	3
Hydrogen, ...	...	0.1	.....	6

Utilization of the Gases Escaping from Blast-furnaces. The gases escaping from blast-furnaces have a very high temperature, and by suitable appliances they may be made to give up their heat, which may then be utilized for heating the blast or the boilers, &c.

Cowper and Whitwell Stoves.—These consist of cylindrical towers with a low-domed roof. The tower is made of wrought-iron plates riveted together and lined inside with ordinary fire-bricks. In *Cowper's stove* the space

within the tower is filled with chequered bricks, *Whitwell's stove* being filled with a serpentine conduit of bricks.

The stoves (whether Cowper's or Whitwell's) are worked in pairs, one stove being heated by the gases from the blast-furnace, whilst the other is heating the blast. They are from 50 to 55 feet high, and vary from 20 to 25 feet in diameter, and cost about £600 each. It is better to use a large number of small stoves rather than a few large ones.

In Cowper's stove (see fig. 24) the heated gases from the furnace enter by the flue *v* into the combustion chamber *m, m*, the necessary quantity of air for their combustion entering by the valve *A*. The hot products travel through the chequer brickwork *t, t* (making it red-hot), and pass thence into the chimney-flue *U*. The stove being heated, the valves *A*, *C*, and *G* are closed, and cold air is admitted through the flues at the bottom of the stove. This cold air rises through the hot brickwork, becoming

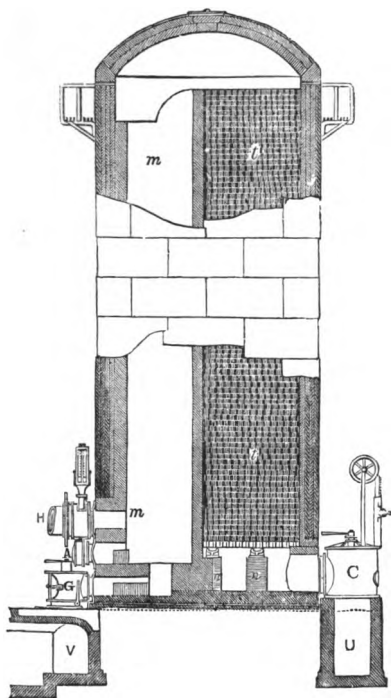


Fig. 24.—Part Sectional Elevation of a Cowper Hot-blast Stove. *A*, Air-valve. *v*, Gas-flue. *G*, Gas-valve. *m, m*, Combustion chamber. *t, t*, Chequer brickwork. *c*, Valve for regulating draught. *U*, Chimney-flue.

more and more heated as it ascends, and escapes through the hot-blast valve H, which has previously been opened. The hot air escaping from H has a temperature of from 700° to 800° C.

In Whitwell's stove the combustion of the blast-furnace

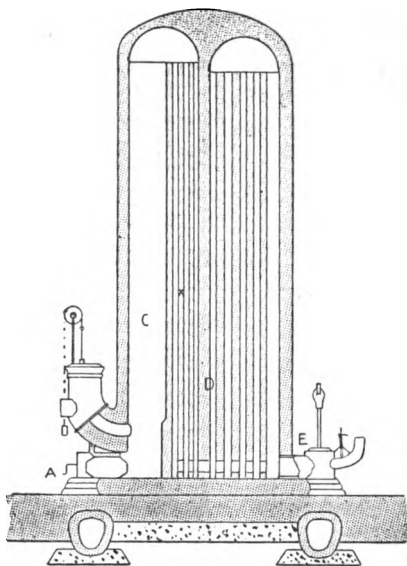


Fig. 25.—Whitwell's Stove. A, Gas-valve. C, Combustion chamber. X, D, Narrow conduits. E, Chimney valve.

gases is more complete, air being admitted at several points to effect a total combustion of the gases. The gases enter the stove at A, and mixing with air admitted by flues into C, are partly burnt, and pass from thence down the narrow conduits X to the bottom. More air is admitted at this point, when complete combustion of the gases ensues (see fig. 25). The heated products pass through another

set of narrow conduits or passages D, and finally pass out through the chimney-valve E. Around the base of the stove are placed spyholes covered with mica; through these the combustion is watched. When the stove is sufficiently heated, the gas, air, and chimney valves are closed and the blast-valve opened, the blast then traversing the heated passages in the opposite direction to that travelled by the furnace gases.

The Cowper stove becomes rapidly choked with dust,

and the friction of the gases against the sides of the stove is also very great. In Whitwell's stove there is twice the heating surface. The Cowper and Whitwell stoves are sometimes combined, and many modifications of the two have also been devised.

Modes of taking off the Gases with Open-mouthed and with Closed-mouthed Furnaces.

Formerly the gases generated in the blast-furnace were allowed to escape, the mouth of the furnace being left open. The tops of modern furnaces are now built in such a way that these waste gases may be collected and utilized. This very desirable object ought to be effected

in such a manner that there shall be no loss of heat from the furnace, and no loss of gas whilst charging. In large furnaces there is a tendency for the gas to follow the walls of the furnace; therefore in charging such furnaces the central

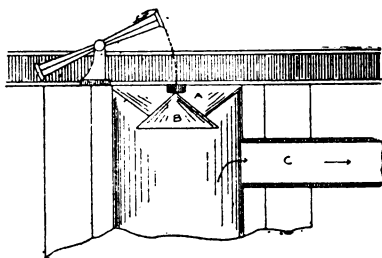


Fig. 26.—Upper Part of a Blast-furnace. A, The fixed cup. B, Movable cone. C, Tube for conveying the waste gases to the Cowper's or Whitwell's stoves.

part of the charge must be made porous. The gases will then tend to accumulate in the centre (where they are most required) and not at the sides.

The gases are taken off from open-mouthed furnaces by a central vertical tube placed in the charge itself, and passing down towards the centre of the furnace; this causes the gases to rush up the centre of the mass of the charge. Frequently a cylindrical hopper is used to distribute the charge, and any gas collecting in the annular space between the hopper and the walls of the furnace is drawn off by iron pipes which pass through the brick-work.

In closed-mouthed furnaces movable cones are employed both for charging the furnaces and for taking

off the waste gas. The simplest forms are usually the best, the complicated forms soon getting out of order from the high temperature to which they are subjected.

The arrangement most frequently used is that termed the "cup and cone" (see fig. 26). This consists of a movable iron cone, B, which descends and so moves away from a fixed cup or funnel-shaped hopper, A, the base of the cone being larger than the rim of the cup. The gases pass through a lateral flue into the main or "take-off" pipe, C. The ore and fuel are placed in the cup, and the cone being lowered automatically or by a hand-wheel, the charge falls into the furnace, after which the cone is raised and so restored to its former position.

Tapping the Furnace. The hole through which the molten metal is tapped out passes through the damstone, and is closed during the working of the furnace by a lump of fire-clay. The fire-clay must not be of too refractory a nature or it will give rise to a "hard tap", and it will then be very difficult to force a hole with an iron bar through this "hard tap" in order to tap or let out the liquid metal.

The molten slag is allowed to run out through a hole about 18 inches below the twyers, and which is therefore above the main tapping hole through which the metal itself is tapped.

The molten iron issuing from the furnace is caused to run into channels made in sand, the main channel being termed the sow, the lateral smaller channels being called the pigs.

CHAPTER X.

VARIETIES OF IRON:—PIG-IRON, CAST-IRON, MALLEABLE IRON, REFINED IRON—THE PUDDLING PROCESS.

Various kinds of Pig-iron. The crude product obtained from the blast-furnace consists of iron combined with varying though small amounts of carbon, silicon, sulphur, phosphorus, and manganese; and sometimes it

also contains a very little titanium, chromium, tungsten, copper, and arsenic. It is termed "pig-iron".

Pig-iron is classified according to the appearance presented by a fractured surface; the character of the surface depending upon the condition of the included carbon.

The carbon is "incorporated" with the pig-iron in a very peculiar manner. If the pig-iron has cooled slowly, the carbon separates out as crystalline small graphitic scales; the iron then is large-grained, and grayish in colour. This is "gray" pig-iron. In some cases only part of the carbon occurs in the graphitic condition, the remainder being combined with the iron. A fractured surface then presents a speckled appearance; and the metal is termed "mottled" pig-iron. The relation of the amount of carbon in the graphitic form, to that in the combined form, depends upon the rate of cooling and on the presence of silicon.

Silicon promotes the formation of graphitic carbon. When pig-iron is rapidly cooled very little of the carbon separates out as graphite; and "white" iron is then produced.

It must be noticed that the total amount of carbon in these three varieties of iron does not vary very much, yet in their physical properties they differ considerably.

The following table shows the proportions of graphitic and of combined carbon in "gray", in "mottled", and in "white" pig-iron.

VARIETIES OF PIG-IRON.

	Gray.	Mottled.	White.
	Per cent.	Per cent.	Per cent.
Combined carbon,	0·08	1·43	3·17
Graphitic or free carbon,	3·40	2·02	0·12
Total,	3·48	3·45	3·29

On remelting gray iron and cooling quickly, white iron is formed; the reverse occurring when molten white iron is cooled slowly.

White iron is produced in the blast-furnace, the first pigs tapped being of this kind. On fusing white iron it passes through a pasty condition before becoming fluid; while gray iron passes quickly from the solid to the liquid state when fused.

White iron is most suitable for the production of malleable iron; gray iron being employed for castings, as it expands on solidifying.

Production of Malleable Iron from Cast-iron. In the blast-furnace the iron becomes carburized, and also combines with other elements, such as silicon, sulphur, phosphorus, &c., all of which must be looked upon as impurities. To produce malleable iron the carbon and these other elements must be removed.

Nature of the Processes, by which the carbon, silicon, &c., are eliminated:—

There must be intimate contact between the pig-iron to be purified, the air, and the oxides of iron used. The pig-iron and the iron oxides must be thoroughly incorporated with one another, or the oxides will either form silicates and pass away into the slag, or will remain as a layer upon the top of the molten mass of iron. As a rule the pig-iron is the first to be acted upon by the oxygen (this gas is supplied from the air, and is also liberated from the oxides of iron). The oxidized iron next yields up its oxygen to the impurities; which are thus oxidized in their turn, and then pass away as part of the slag, or are removed as gases.

The processes by which purification of blast-furnace iron is effected are:—1st, The Open-fire or Finery process; 2nd, The Refinery process; and 3rd, The Wet and Dry Puddling processes.

Slags or Cinders produced in Finery Processes. The "slags" formed during the finery processes are highly basic, the proportion of ferrous oxide (FeO) to the silica (SiO_2) contained in them being very high. The chemical composition of such slags may be represented by the formula $3\text{FeO} \cdot \text{SiO}_2$.

They also contain oxide of manganese; and the pre-

sence of this substance, together with the ferrous oxide, makes the slags very fusible and fluid.

Basic silicates pass rapidly from the solid to the liquid state, and *vice versa*; and soon cool after they have solidified. When cold they are brittle, and break "short".

Running-out Fire or Refinery. Refining sometimes, but not often, precedes puddling. A molten layer

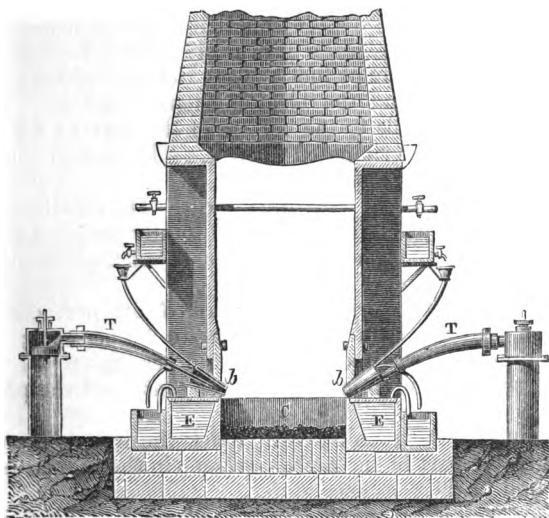


Fig. 27.—Refinery Hearth. *c*, The hearth. *E, E*, Hollow water-jacketed walls. *t, t*, Blast-pipes. *b, b*, Twyers.

of iron is exposed to a blast of air from inclined twyers; the silicon and part of the carbon are thereby removed, and a large quantity of slag and cinder is formed. By this process gray iron is converted into white iron by rapid cooling.

The bottom of the hearth is of grit, fire-brick, or argillaceous sand; the hearth, *c*, is bounded at the back and sides by hollow iron castings, *E*, through which water constantly circulates. The front of the hearth is closed by

a cast-iron plate having a tap-hole (see fig. 27). The hearth is surmounted by a brick chimney. In front of the furnace is a casting mould, also made of cast-iron, supported by long cisterns, through which cold water flows. The refined iron on entering the mould is rapidly cooled, carbon is not able to separate out as graphitic scales, and white iron is thus produced.

The furnace is filled with ignited coke or charcoal to the level of the twyers, *b, b*; on this is placed a mixture of scrap-iron and pig-iron previously heated to redness, together with layers of fuel. Slags rich in ferrous oxide are also added; and the blast is then turned on. The iron melts and falls to the bottom of the hearth; a layer of slag being superimposed upon it. The molten iron is then run into the casting mould.

Composition of Refined Iron. During the process of refining, the silicon is almost totally removed from the iron; the phosphorus, however, is but slightly acted on.

An iron which originally contained 2.6 per cent of carbon, had this reduced by refining to 2.3 per cent; the silicon present was reduced from 2.0 per cent to 0.1 per cent; the sulphur from .5 to 0.4 per cent; and the phosphorus from 0.9 to 0.8 per cent.

Owing to the rapidity with which the iron is cooled, the greater part of the carbon present in the refined iron is found in the combined state.

Composition of Refinery Slags or Cinders. Refinery slags are essentially monosilicates of iron, containing two atoms of oxygen in the base, and two atoms of oxygen in the acid, as represented by the formula $2\text{FeO} \cdot \text{SiO}_2$.

The Puddling Process. Henry Cort invented the "puddling" process, and patented it in 1774. It is essentially a process for refining pig-iron in a reverberatory furnace. The atmosphere of the puddling furnace must be oxidizing, and the iron is purified both by the action of this oxidizing atmosphere and by the oxygen derived from the slag. The bed of the furnace is hori-

zontal, the bath of molten metal being of small thickness. The mass of iron must be energetically and continuously stirred in order that every part of it may come into contact with the oxidizing agents. By this means the silicon, manganese, phosphorus, sulphur, and carbon are converted into oxides; and are then eliminated in the above order. Great use is made of the damper; for, by admitting or excluding air, the temperature of the furnace may

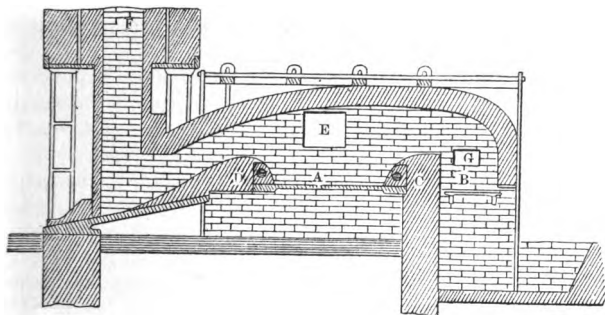


Fig. 28.—Puddling Furnace. A, Hearth. B, Fire-grate. C, Fire-bridge. D, Flue-bridge. E, Working-door. F, Chimney. G, Fire-hole.

be raised or lowered at will, and the process arrested at any stage.

Pig Boiling and Dry Puddling Furnace. The puddling furnace consists of a reverberatory furnace provided with a low roof which slants from the fireplace to the flue (see fig. 28). The bed, A, is formed of iron plates; the fire-bridge, C, and flue-bridge, D, consisting of hollow iron castings encased and surrounded by fire-brick. The sides of the furnace are also composed of hollow iron castings, through which cold water circulates to prevent their fusion. The laboratory or working part of the furnace is about 6 feet long and 4 feet wide, tapering slightly towards the flue-bridge. The working door, E, and the fire-hole, G, are on the same side of the furnace, the area of the fire-grate, B, varying from one-third to one-half the area of the laboratory. The working door is

made of fire-bricks set in an iron frame, the frame being attached to a lever by which it can be raised or lowered.

The roof of the furnace is made of siliceous bricks, the flame from the grate impinging upon the roof, and being deflected by it on to the metal. The furnace bed was originally lined with sand, but this has of late years been replaced by red oxide of iron, hammer-scale, slags rich in iron oxide, ilmenite, and other compounds rich in oxygen. The sides of the furnace are covered with "bulldog", a substance rich in oxide of iron; this covering is known as the "fettling".

Invention of Iron Bottoms. The most important improvement in connection with puddling furnaces is the introduction of iron sides and bottoms. Fusion of the iron in these parts is prevented by allowing water to pass through hollow iron castings and so cooling the sides of the furnace. Before iron was employed in this manner, the walls of the puddling furnace were constructed of siliceous bricks, the bottom being covered with sand. As a consequence of this, the siliceous materials furnished silica, which, combining with the oxide of iron, yielded a silicate of iron; thus robbing the furnace of oxygen and also causing a waste of metal.

Manipulations in the Puddling Process. The manipulation of the puddling process differs according to the nature of the pig-iron to be refined.

Dry Puddling. This is the original process introduced by Cort, and is available for pig-iron containing a comparatively small amount of carbon. It may be divided into three stages:—1st, fusion; 2nd, stirring; 3rd, formation and treatment of the blooms.

Five or six hundredweights of pig-iron are heated at a time, hammer-scale and rich slags being added. The working-door is closed; the damper is opened, and the mixture fuses to a pasty mass in about 20 minutes. The ingredients of the imperfectly fused mass are now thoroughly mixed by stirring them with a curved rod called a "rabble", so causing the slag and the iron to become incorporated. First the silicon and manganese,

and then the phosphorus become oxidized, and pass into the slags; the sulphur in its turn also becomes oxidized and passes off as sulphur dioxide gas. Lastly, the carbon is oxidized and is eliminated partly as carbonic oxide gas, and partly as carbon dioxide gas. As the iron becomes purer, it becomes less fusible; the temperature is therefore gradually increased by regulating the damper, and the iron becomes united together and gathers into large masses, or "comes to nature" as the workmen say. The carbonic oxide escaping from the pasty mass burns, giving rise to "puddler's candles".

This first part of the process lasts from 20 to 30 minutes, a flat, sponge-like mass of iron full of entangled slag being produced. The temperature is now again raised, and these large portions are divided into smaller blooms. Finally the pasty "blooms" or balls of iron are removed to the steam-hammer, and the liquid slag is there hammered or squeezed out, the carbonic oxide also escaping and burning all the time.

Wet Puddling or Pig Boiling.—This process is less rapid and more costly than the dry method, and is only used for refining gray pig-iron rich in carbon. It may be divided into three stages as in dry puddling.

But, unlike the process of dry puddling, there is in "wet puddling" a complete fluidity of the bath of molten iron within the furnace; the melting down requiring from an hour to an hour and a quarter. Siliceous pig-iron rich in carbon is used, and if steel is required manganese pig-iron must be employed. The bed of the furnace being composed of an oxidized slag, the molten iron lies between a lower oxidized slag and an upper basic slag which floats upon its surface. The iron is either completely decarburized, or only just sufficient carbon is left to form steel.

The silicon, manganese, phosphorus, sulphur, and carbon are removed in the order named, each and all being oxidized and then either passing into the slag or being removed as gases. In the last stages of the process the oxygen combines directly with the carbon, producing car-

bonic oxide, which causes the mass of iron to swell and bubble up, while jets of gas escape. All this occurs during the rabbling or stirring of the molten bath. We thus get two subdivisions of the period of rabbling:—(1) Scorification and removal of the silicon, manganese, &c.; (2) Decarburization of the iron by the formation of carbonic oxide, this latter being known as the “boiling phase”. As the amount of carbon diminishes, the temperature of the furnace must be raised, when the metallic mass agglutinates and becomes spongy. The process must be arrested as soon as the carbon has been removed, or the iron itself will begin to oxidize.

When manganese is present, the puddling can be arrested so as to leave just enough carbon to form a definite shade of steel. The manganese retards the decarburization of the iron by reducing the Fe_3O_4 to FeO , which change would otherwise be effected by the carbon. So that when the iron contains manganese, the strong affinity of this latter metal for oxygen retards the formation of Fe_3O_4 .

The spongy mass of iron is collected into balls and hammered or squeezed to extract the slag. The hammered or shingled mass still contains silicon, manganese, carbon, phosphorus, and sulphur in small quantities, probably contained in the included slag which has not as yet been completely removed.

Composition of Tap-cinder. The slag from the puddling furnace is termed “tap-cinder”. It is practically a silicate of iron, containing two atoms of oxygen in the base, and two atoms of oxygen in the acid. Its chemical composition may be represented by the formula $2\text{FeO} \cdot \text{SiO}_2$. This shows it to be a monosilicate derived from silicic acid $\begin{array}{c} \text{HO} \diagup \text{Si} \diagdown \text{OH} \\ \text{HO} \diagdown \text{Si} \diagup \text{OH} \end{array}$, by substituting for the four hydrogen atoms in the hydroxyl groups (OH) two atoms of iron, thus $\text{Fe} \begin{array}{c} \diagup \text{O} \diagdown \\ \diagdown \text{O} \diagup \end{array} \text{Si} \begin{array}{c} \diagup \text{O} \diagdown \\ \diagdown \text{O} \diagup \end{array} \text{Fe}$.

Many of the impurities originally contained in the iron pass into and are found in the “tap-cinder”—

phosphoric acid and silicate and oxide of manganese, for instance. The slag becomes more and more pasty as its components become oxidized, the ferrous oxide (FeO) becoming changed into ferric oxide (Fe_2O_3), thus making the mass more infusible.

CHAPTER XI.

WORKING OF PUDDLED IRON: ITS CONVERSION INTO FINISHED IRON, TIN-PLATES, &c.

Working of the Ball. To prepare the puddle balls or "blooms" for the rolling-mills, they must undergo the process known as "shingling". This is the name given to the operation by which the slag is hammered or squeezed out, and the iron rendered compact and more uniform in structure. This process of "shingling" or "blooming" is effected either by steam-hammers, or by squeezers moved by steam power or by water-wheels.

Forge Hammers. The forge hammers by which the blooms of puddled iron are worked into flat cake-like masses suitable for passing between the rolls, are very varied in form.

In many iron-works the old forms still exist, as the tilt and helve hammers;

but these are being gradually replaced by the steam-hammer invented by Nasmyth. The advantages of this hammer are that it takes up but little room as compared with the old helve hammers, and also that the force of the blow can be varied with the work to be done.

Tilt Hammers. These consist of a wooden shaft hooped with wrought-iron; this shaft acts as a lever working on a fulcrum (see fig. 29). To one end of the shaft is attached the head or hammer, H, which weighs

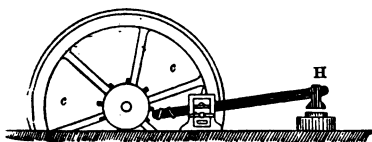


Fig. 29.—Tilt Hammer. H, Hammer-head.
c, c, Cam-wheel.

from 5 to 10 cwts., and which falls upon an anvil placed below. The other end of the shaft is depressed at intervals by the teeth of a revolving cam-wheel, *c, c*, worked by steam-power. The head is thus raised as each tooth of the cam-wheel passes, and then falls by its own weight.

Helves or Lift Hammers. These consist of heavy levers of cast-iron working on a fixed fulcrum, *F*, at one

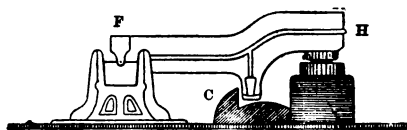


Fig. 30.—Helve Hammer. *F*, Fulcrum. *H*, Hammer
c, Cam-wheel.

end, and having the head or hammer, *H*, attached to the other end. They are raised by a cam-wheel, *c*, and fall by their own weight (see fig. 30).

In the “belly-helve” the cam-wheel is placed partly below the surface of the ground; each projection of the cam-wheel acting on a projecting piece of iron forming part of the lever or shaft of the helve, and termed a “bray”. The hammer is thus raised from 10 to 40 inches, and falls when the tooth of the cam-wheel passes.

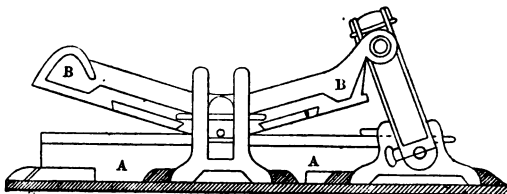


Fig. 31.—Double Crocodile-squeezer. *A*, Lower jaw. *B*, Upper jaw.

The anvil upon which the puddled iron is placed is made of wrought-iron, and is attached to a heavy casting to give it steadiness.

Squeezers. By the use of “squeezers” the welding of the puddled ball and the removal of the included slag are effected by *pressure*, and not by impact as in the case of the hammers. Two kinds of squeezers are in use: (1) the lever, and (2) the rotatory squeezer.

The crocodile-squeezer belongs to the former class. The lower jaw A, of this squeezer is fixed, the upper jaw, B, alone being movable (see fig. 31). The under surface of the movable jaw, where it comes into contact with the ball of iron, is ribbed or serrated. The upper jaw is moved by a crank connected with the engine. The bloom of puddled iron is inserted between the open jaws of the squeezer, and is gradually rolled by the workman from the wide end to the narrow end. The slag contained within the bloom is thus expelled, and the particles of iron welded together to form a coherent mass.

Rotatory Squeezers. These consist of a revolving cylinder (*a*), the surface of which is roughened or studded with teeth (see fig. 32). This cylinder is placed eccentrically with regard to the outer casing (*b*), which is also roughened internally. The ball of iron is introduced into the wide space (*c*), and is then carried forward by the motion of the cylinder (*a*).

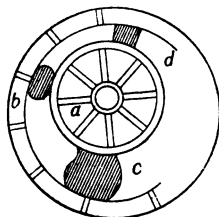


Fig. 32.—Rotatory Squeezer. *a*, Revolving cylinder. *b*, Outer casing. *c*, Entrance. *d*, Exit.

Since the space between the cylinder and the outer casing gradually diminishes, the ball is squeezed or compressed into less volume, and leaves the space (*d*) in a condition ready for rolling. As the distance between the cylinder and the outer casing is fixed, the balls of iron to be introduced must always be of an uniform size.

Puddling or Puddle Rolls. The forge-train consists of two sets of rolls, the roughing rolls, A, and the finishing rolls, B (see fig. 33). The roughing rolls (through which the hammered cake of puddled iron is first passed) are about 5 feet long, and about 20 inches in diameter; they are so adjusted as to form a series of diamond-shaped grooves between them, which diminish regularly in size from one end to the other. The distance between the rolls is determined by adjusting the screws (*a*), and the connection between the two rolls is established by means of the cogs attached at *b*, *b*, (see fig. 33). The necks or

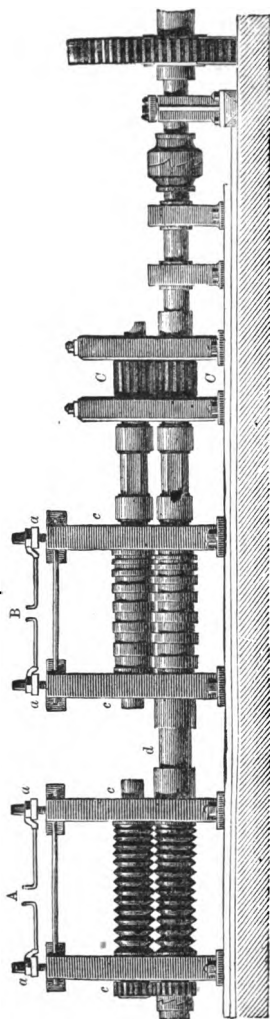


Fig. 83.—Forge-train, or Mill for Rolling Puddled Bars. A, Roughing rolls; B, Finishing rolls; a a, adjusting screws; b b, connecting cogs; c c, cast-iron "housings"; d, coupling.

"journals" of the rolls run in metal bearings, which are supported in cast-iron "housings" (c, c).

The finishing rolls are arranged similarly to the roughing rolls, but have rectangular channels instead of the diamond-shaped grooves. These channels also diminish in size from one end of the rolls to the other. The two sets of rolls are connected together by couplings (d), keyed tightly together. The two rolls of each pair therefore revolve with the same velocity, while the roughing rolls make 70 revolutions per minute, and the finishing rolls 90 revolutions per minute.

Both sets of rolls are reversible, so that after the cake of iron has been passed through in one direction, the rolls can be reversed or caused to revolve in the opposite direction, and the iron is then returned through the rolls back again.

Each bloom of iron is passed successively through the grooves of the roughing rolls, commencing with the largest groove, until

the bloom is reduced to a square bar small enough to enter the channel-like grooves of the finishing rolls. In the finishing rolls the reduction of the iron rod is continued until a puddled bar of the desired thickness is obtained.

Working of the Puddled Bar into Merchant or Finished Iron. The bars of iron which have been obtained by shingling, squeezing, and rolling the blooms of puddled iron, are still of an inferior quality. To improve the quality of the iron and to make it more *fibrous* the puddled bars are cut into short lengths and reheated in a special

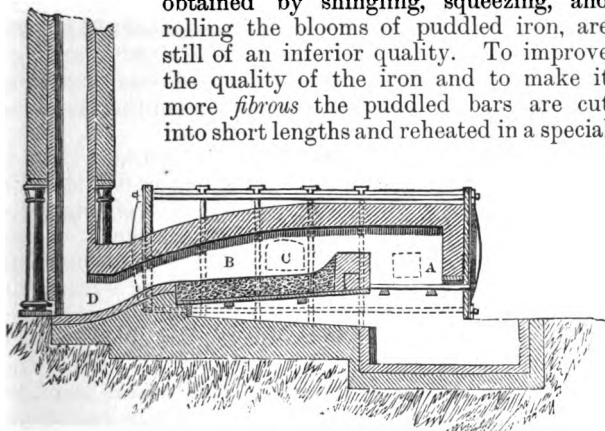


Fig. 34.—Reheating Furnace. A, Fire-grate. B, Hearth. C, Working-door. D, Flue.

furnace, and are then again hammered or rolled into any desired form.

Reheating Furnace, with Coal as Fuel. In this process the forged bars and shingled masses of iron, which, it must be remembered, still contain some slag disseminated through their mass, are reheated on the bed of a reverberatory furnace, where they are made to yield up the slag and other impurities which they contain. The slag when heated gives up certain silicates, termed neutral silicates, which being very fluid flow away, leaving a more or less pasty residuum of basic silicates in the iron. These basic silicates react upon the metallic fluid mass, combining with the phosphorus, silicon, and other impurities. The latter substances are in fact thus

converted into oxides, which pass away in and along with the fluid mass of neutral silicates or slag.

The reheating furnace is of the reverberatory type, and resembles the puddling furnace, but has a greater area of fire-grate, A, compared with the volume of the laboratory part, B, than is the case with the puddling furnace (see fig. 34). The bed is usually horizontal, but it is sometimes inclined towards the flue, D, to admit of the melted slag running off. It was formerly lined with sand or quartzose clay, but these materials have of late years been replaced by pure iron ores. The slag from the reheating furnace is termed "flue-cinder".

Piling to produce Merchant Iron. This is effected by cutting puddled bars into suitable lengths, packing them into oblong piles (binding them together with iron bands or wire), and raising them to a welding heat in a reheating furnace. On removing each pile from the furnace it is at once passed through the rolls, and then forms "merchant bars", or it may be rolled into iron sheets or into any desired form.

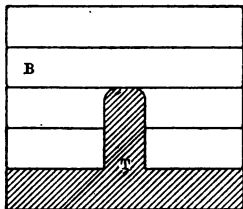


Fig. 35.—Section of Piled Bars
B, Unfinished bars. T, T-shaped piece.

The arrangement of the puddled bars forming the piles varies at different foundries. The commonest method is to place a number of new unfinished bars between two finished bars and then to weld the whole together. Another method is to weld a number of bars, B, on a T-shaped piece T (see fig. 35).

Varieties of Sheet Iron and Slit Rods. For making iron plates puddled bars are made into piles, heated in the reheating furnace, and afterwards rolled to the required thickness between smooth rolls. The thin plates intended for tinning are called "black-plates", and are doubled over upon themselves after reheating, so that several sheets are rolled together. The plates are afterwards cut to the proper size and separated.

Tin-plates. In the year 1720 works were erected at Pontypool for the manufacture of "tin-plates"; and these were the first works in England where the art of coating iron plates with a thin layer of iron-tin alloy was successfully practised. It was not, however, until the year 1783 (when Henry Cort invented the grooved rolls) that the tinning of iron plates attained a good position as an important British industry.

On leaving the plate-mill the thin iron plates are separated, sprinkled with sawdust to keep them separate or apart from one another, and immersed or "pickled"

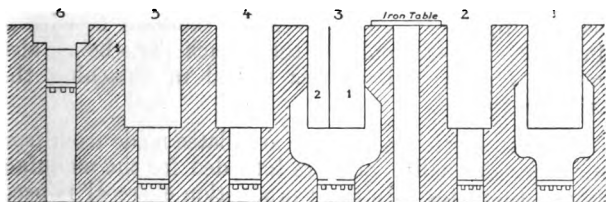


Fig. 36.—Tin-plate Plant.

in dilute sulphuric acid. They are then heated for about 24 hours, passed through the cold rolls (to remove any iron scale), and again heated at a low heat. The plates are then washed in dilute sulphuric acid, and finally are well scoured with sand and water. The plates now look very bright and *clean*, and are ready to be tinned.

The tinning compartment contains at least six pots, each heated by a separate fire. They are named as follows:—1, The tinman's pot; 2, the tin-pot; 3, the dipping-pot; 4, the grease-pot; 5, the cold-pot; 6, the list-pot (see fig. 36).

The *tinman's pot* contains melted grease, and into this liquid the iron plates are immersed. They are then removed to the *tin-pot*, and are there plunged into molten tin, which is covered with a layer of grease. The plates here receive an irregular coating of tin, and are immediately transferred to the *dipping-pot*, which is divided into two compartments, each compartment containing molten tin

and grease. After being plunged into the first compartment the plates are removed and wiped over with a brush; to remove the brush marks the plates are dipped into the second compartment, which contains the purest tin.

The plates are now passed on to the *grease-pot*, which is full of melted grease, the object of this being to allow any superfluous tin on the plates to run off. They are then removed to the *cold-pot*, which contains tallow heated only to a low temperature. Here the plates cool slowly, and are annealed. Finally, in the *list-pot* is a little molten tin (which is at a temperature much above its melting-point), in which the lower edge of each plate is dipped in order to remove the bead or wire of tin which has accumulated there, each plate being also smartly tapped with a stick to aid in detaching the excess of tin.

Charcoal Plates. These are plates made from iron of a superior quality, and are intended for the manufacture of tin-plates. In their production charcoal is used in the *fineries* and in the *reheating furnace* instead of coke. Less impurities are thus introduced into the metal, and it is consequently more malleable, and can be more easily rolled out to form the thin black-plates which are required for tinning.

CHAPTER XII.

CONVERSION OF IRON INTO STEEL: THE BESSEMER PROCESS, &c.

Classification of Processes for Production of Steel. The various processes for producing steel may be classified as follows:—

- 1st. By direct methods, as in the Catalan forge, the Hindoo and Burmese forges, &c.
- 2nd. From pig-iron in the finery.
- 3rd. By puddling pig-iron.

4th. By the cementation process, and the case-hardening process.

5th. By the heating of blister steel, pure iron oxides, or iron with carbon in crucibles.

6th. By the Bessemer and Thomas-Gilchrist processes.

7th. In open hearths, such as Siemens', Pernot's, Ponsard's, and Dick's furnaces.

Carburization of Bar-iron. The wrought-iron to be carburized must consist of the best Swedish, Russian, or Low Moor bar-iron. On surrounding bar-iron with carbonaceous matter and raising its temperature to from 1000° to 1170° C. conversion of the wrought-iron into steel takes place without any fusion of the iron.

The bars of iron employed in this process are from 2 to 5 inches broad, and from $\frac{5}{8}$ to $\frac{3}{4}$ of an inch thick. A layer of powdered charcoal is spread evenly over the bottom of each chest; upon this are placed the bars with their flat sides down, but not touching one another. A layer of two inches of charcoal is placed over the bars; and upon this more bars are laid, and so on until the chests are filled. The whole is then covered with scraps of siliceous grit (from grindstones), termed "wheelwharf", and this frits and forms a protecting layer. A hole is left at the end of each chest communicating with the exterior of the furnace, and in this hole bars of wrought-iron ("trial bars") imbedded in charcoal are placed. These trial bars are withdrawn at intervals, and their fracture indicates the degree of carburization. The furnace fire is lighted and the temperature gradually raised, the whole process lasting 6, 7, or 8 days. From 16 to 18 tons of bar-iron are usually treated at the same time in one furnace. The degree of carburization is different for different purposes, and it is never uniform, the exterior of each bar always containing more carbon than the interior. The product is termed "blister" steel, owing to the surface of each bar being covered with blisters, due in all probability to the reduction of oxide of iron in the inclosed slag and the evolution of carbonic oxide. Great care must be taken not to allow the tem-

perature to exceed 1170°C. , or the surface of the iron is fused, and "glazed" bars are formed. If air is admitted the bars have a rough surface, and a thin film of iron is produced upon each bar. Such "glazed" and "aired" bars are unfit for making crucible steel. The increase of weight gained by the bars during the converting process is about 4 lbs. per ton.

For every ton of steel produced, $13\frac{1}{4}$ cwts. of charcoal are required.

How does the carbon find its way into the iron? All forged bars contain thin layers of silicate of iron, and the carbon acting upon this compound at a high temperature reduces the iron contained in it to the ferrous condition. Ingot metal, which is free from this cinder or iron silicate, is carburized much less rapidly than puddled wrought-iron, and the characteristic blistered surface is not produced. The presence of cinder must also play an important part in promoting the penetration of the carbon.

It seems probable that carbon is conveyed into the bars by the gaseous compounds of carbon, as carbonic oxide and certain hydrocarbons. Carbonic oxide gas being formed is absorbed or occluded by the metal; on an elevation of temperature this carbonic oxide is decomposed, and the liberated carbon combines with the iron. Thus:—



The liberated carbon dioxide then combines with more carbon (from the charcoal in which the iron is embedded), forming more carbonic oxide, which is again decomposed:—



The same charcoal can, however, only be used a few times.

Converting Furnace. The converting furnace, in which the carburization of bar-iron is effected, consists

of two rectangular chests of siliceous stone, C, C, arranged one on each side of the fireplace, g, which traverses the whole length of the furnace.

Beneath these chests are horizontal flues, o, o, which are continued vertically between the external walls of the furnace and the sides of the chests (see fig. 37). The roof is arched, and is traversed by flues to allow of the escape of gases, &c. The walls of the chests are about 6 inches thick, and each chest is from 12 to 14 feet in length; they are about 3 feet 6 inches in width and depth. The furnace rests upon solid masonry to totally exclude the air, the flues and roof being made of fire-brick.

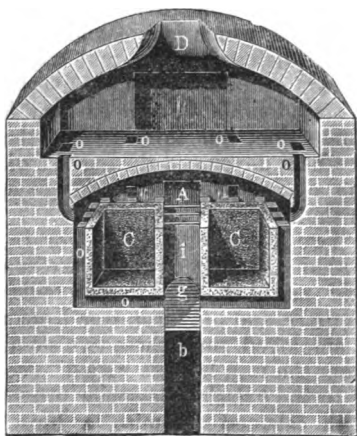


Fig. 37.—Cementation Furnace. c, c, Rectangular chests. o, Fireplace. o, o, Lateral flues. b, Ash-pit. D, Chimney.

Carburization by Fusing Compact Iron with Carbonaceous Matter. In the Bessemer, Siemens-Martin, and Huntsman processes the carburization of iron is brought about by adding carbon to molten iron. But direct combination of iron and carbon is attended with some difficulty. If, however, a compound of iron, manganese, and carbon is added to the molten iron, carburization of the latter metal takes place rapidly, and steel is produced. The compound of iron, manganese, and carbon used for this purpose is called *spiegeleisen* or "mirror-iron", owing to the brilliant faces presented by crystals of this compound.

Spiegeleisen is really a variety of white pig-iron, and it may be added to the molten iron contained in the

Bessemer converter or in the Siemens furnace either in the solid or in the molten condition.

Bessemer Process for the Manufacture of Steel. This process was patented by (Sir) Henry Bessemer in 1855. Essentially the process is conducted in a large iron vessel called a *Converter*, through the bottom of which jets of highly-compressed air enter, this air oxidizing, heating, and stirring up the molten bath of iron contained in the converter as it rises through it. A considerable amount of heat is lost by radiation and conduction, but this is more than compensated for by the heat developed during the oxidation and burning of the silicon, phosphorus, manganese, and carbon present in the iron.

Two distinct modes of working are adopted. In the "Acid" Bessemer process the converter is lined with an acid material, *i.e.* a highly siliceous sandstone termed ganister, and only iron free from sulphur and phosphorus is employed, since these two elements cannot be removed from the iron by this "Acid" process.

In the "Basic" Bessemer process the converter is lined with calcined dolomite, a limestone consisting of the carbonates of lime and magnesia, and which is a basic material. By thus employing a basic lining both sulphur and phosphorus may be eliminated from pig-iron.

When starting an operation incandescent coke is charged into the converter, and the blast is turned on at a low pressure. As soon as it is sufficiently heated, the converter is brought to a horizontal position, so that the molten pig-iron which is run into it will not touch the twyers. The pig-iron is either run directly from the blast-furnace or it is melted in a special cupola communicating with the converter by channels lined with fire-clay. The blast is now increased, and the converter returned to the vertical position. Streams of air issue rapidly from the twyer holes, and bubble upwards through the molten metal. Two and sometimes three distinct phenomena now occur. First, there is a true scorification and second, a true decarburization. In the first,

the silicon, manganese, and a little iron are oxidized and converted into fixed oxides, as silica, &c. This constitutes the "quiet" stage.

After the removal of the silicon and manganese the second stage sets in; the carbon becomes oxidized and is converted into carbonic oxide and carbon dioxide, and these gases escaping upwards through the molten iron causes it to "boil". When this "boiling" begins, the flame at the mouth of the converter increases in volume, slight detonations occur, and decarburization of the iron ensues. At this stage the carbon is oxidized chiefly by the upward passage of air through the molten iron, and not by the action of dissolved oxides as in the puddling process.

As the carbon disappears and the boiling ceases the flame drops and assumes a brownish colour; the iron is now being oxidized. During the whole process abundant fumes are evolved, these being due to the escape of oxides of iron, silicon, and manganese.

Theoretically the process might be stopped at any stage of decarburization, and the product (wrought-iron) poured into moulds. This is very rarely done, the blowing being continued until the whole of the carbon is removed.

To convert the molten wrought-iron in the converter into *steel* it becomes necessary to recarburize it: spiegel-eisen is therefore added. When we do not want to recarburize the iron, ferromanganese is added. The spiegeleisen not only recarburizes the iron, but its manganese acts on the dissolved iron oxide and removes it. When the spiegeleisen is added a new ebullition is set up, carbonic oxide being given off, but this second boiling is less pronounced than the first. The manganese also improves the quality of the steel.

The entire operation requires from 15 to 30 minutes. Phosphorus, however, cannot be removed by the "Acid" Bessemer process. In 1835 Berthier showed that in order to remove phosphorus from iron, the slags formed during the process must be basic. Snelus in 1872 patented

a basic lining for the Bessemer converter, but did not develop the process. In 1874 Messrs. Thomas and Gilchrist patented their process, which consisted of a lining of silicate of soda and limestone. Another composition which answers the same purpose consists of powdered calcined dolomite rendered adhesive by the addition of tar.

The pig-iron usually employed in this "Basic" process contains from $\frac{1}{2}$ to 1 per cent of silicon, .8 to 3 per cent of phosphorus, under .3 per cent of sulphur, and not more than $2\frac{1}{2}$ per cent of manganese. The best results are obtained from pig-iron containing about 3 per cent of phosphorus, the best steel being obtained from Scotch and Staffordshire pig-iron. The process is similar to the "Acid" process, but when the point is reached at which the ordinary "Acid" process is stopped, the "Basic" process is continued for from 100 to 300 seconds longer. This continuation of the blast is termed the "after-blow", and is absolutely necessary if the phosphorus is to be eliminated. The basic slags resulting from this process contain more iron than the slags from the "Acid" process, and are returned to the blast-furnace to be re-smelted.

The molten steel contained in the converter is now cast into ingots, the converter being brought to the horizontal position and the metal run into a large iron ladle lined with ganister or calcined dolomite. This ladle is conveyed by a crane to a position over the ingot moulds, and the molten steel is then allowed to flow into the moulds by removing a plug from a hole in the bottom of the ladle.

Many attempts have been made to roll the steel ingots before they cool (so as to save reheating), but although the outside may have solidified, the interior of the ingots is still fluid or pasty. Consequently the ingots are usually allowed to cool, and are then again reheated in some form of reverberatory furnace. To obviate the necessity for reheating, Giers introduced "soaking pits". These consist of pits built of brick and lined with fire-clay; they

are rather deeper than the ingots are long, the ingots nearly filling the pits; the top of the pits, however, being from 6 to 18 inches above the top of the ingots. By means of a crane the hot ingots are transferred from the moulds to the soaking pits, and are left there for twenty to thirty minutes, the top being closed with a cover.

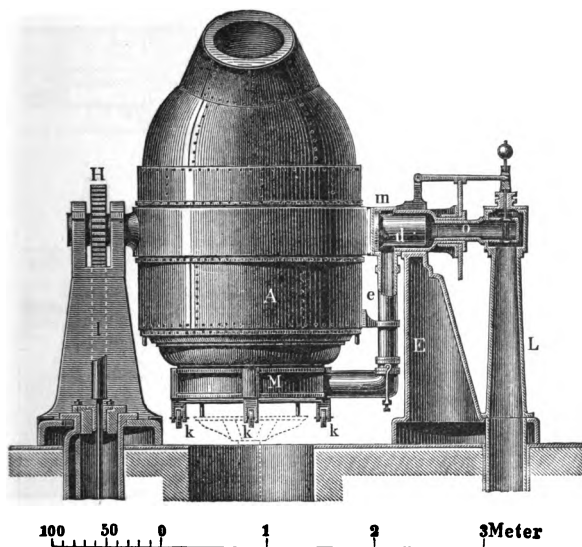


Fig. 38.—Bessemer Converter. A, Body of converter. M, Twyer box. k, k, Castors on which to remove twyer box. R, I, Standards for supporting the converter. m, Trunnion. H, Gearing for tipping the converter. L, o, d, e, Hollow blast-pipe.

The atmosphere of the pits is furnished by the gases given off from the hot steel, and consists of nitrogen 63 per cent, hydrogen 25 per cent, and carbonic oxide 8 per cent. The heat of these gases is returned to the cooling sides of the ingots; and these being uniformly heated cool uniformly also, and may be rolled directly afterwards.

Description of the Apparatus used in the Bessemer Process. The Bessemer vessel or "con-

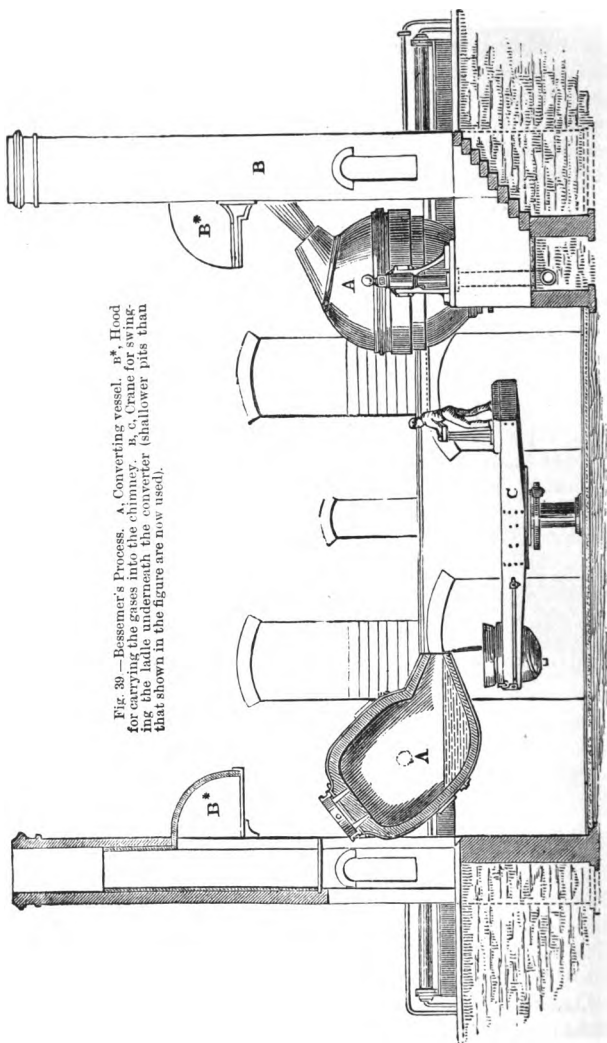


Fig. 39.—Bessemer's Process. A, Converting vessel. B*, Hood for carrying the gases into the chimney. B, C, Crane for swinging the ladle underneath the converter (shallower pits than that shown in the figure are now used).

verter", A, is made of various sizes, capable of holding from 3 to 15 tons of metal at each charge; and these are called respectively 3, 5, 10, and 15 ton converters (see fig. 38).

A 6-ton converter is 8 feet in height, and 12 feet 6 inches in diameter. The wrought-iron plates of which

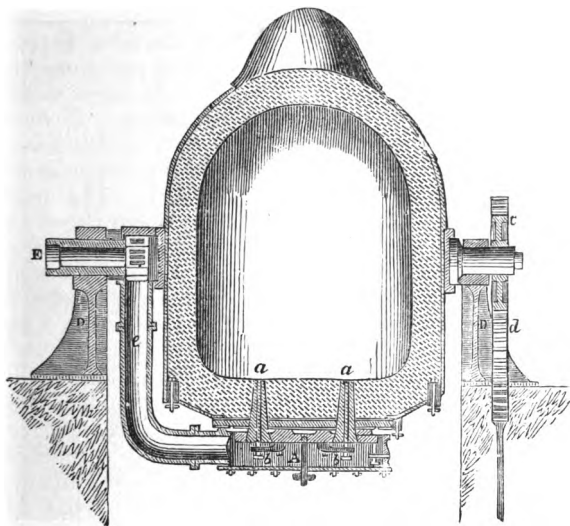


Fig. 40.—Vertical Section through the Bessemer Converter. A, Twyer box. a, a, Twyers. D, D, Standards. E, Hollow trunnion. e, Blast-pipe. d, Tipping gear.

the converter is made are $\frac{3}{4}$ inch in thickness, and are riveted together. The converter is lined either with *ganister*, as in the Acid Bessemer process; or with *calcined dolomite*, as in the Basic Bessemer process (see fig. 40).

The bottom of the converter is removable, being simply bolted on to the body of the vessel; its inner surface is flat, and is penetrated by from 7 to 12 conical clay twyers, *aa* (see fig. 40), 20 inches in length, each twyer having 12 apertures for the admission of the blast. Below the

twyers is the twyer box, A, connected by a curved pipe, e, with the hollow trunnion of the converter, E, and thereby with the blowing apparatus (see fig. 40).

The converters are usually worked in pairs, one on either side of a casting pit. This pit contains the ingot moulds into which the molten metal is poured. In the centre of the pit is a hydraulic lift, to the top of which is attached a platform of wrought-iron girders carrying at one end the casting ladle into which the metal is poured

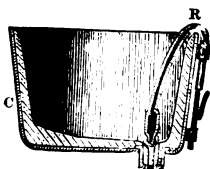


Fig. 41.—Bessemer Casting Ladle. C, Casting ladle. R, Iron rod.

from the converter, and from which it is tapped into the ingot moulds.

The casting ladle, C, is formed of iron plates riveted together, and is also lined with ganister or dolomite (see fig. 41). The molten metal is tapped into the ingot moulds from the bottom of this ladle, by removing a vertical iron rod, R, which is covered with fire-

clay, and one end of which fits into a hole at the bottom of the ladle.

Casting of Steel. A process for making cast or crucible steel was patented by Huntsman as long ago as 1740. An extremely high temperature is required, and this is now obtained by using a Siemens regenerative furnace. The steel is melted in skittle-pots, the level of the furnace being on the same level as the floor. "Blister" or cementation steel is melted in the crucibles and cast into ingots. The cast-steel is usually termed "Huntsman" steel.

Mushet afterwards patented a process for preparing cast-steel by heating together malleable bar and scrap iron with carbonaceous matter. Later on, he substituted pure iron ores for scrap-iron. In 1839, Heath added a so-called carburet of manganese, prepared by heating together charcoal and manganese oxide, and obtained a more homogeneous metal than had hitherto been the case. It was afterwards discovered that the preliminary heating together of the charcoal and manganese oxide was not

necessary; the same results being obtained if the two were added to the molten iron separately.

Cast-steel can also be made by melting up malleable iron and scrap steel mixed with powdered charcoal and speigeleisen.

Furnaces and Crucibles for the Casting of Steel. The furnace in which the manufacture of cast-steel is effected consists of a number of rectangular holes on a level with the floor; each hole is lined with ganister or fire-bricks, and is about 3 feet deep by 2 feet

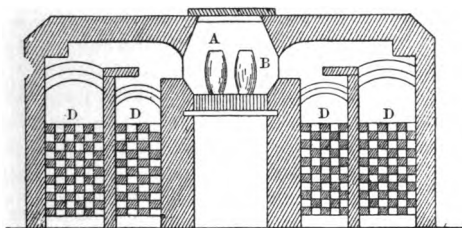


Fig. 42.—Furnace for Cast-steel. A, Furnace. B, Crucibles. D, D, Regenerator.

square (see fig. 42). Each hole, A, contains two crucibles or melting pots, B, covered with lids; and from each hole a flue conveys the products of combustion to a square chimney-stack. Formerly, coke was burned around each crucible; but coke-fires have been superseded by gas-furnaces upon the Siemens regenerative principle, D, D. The crucibles are made of a mixture of fire-clay with burnt-clay and coke-dust; and are from 16 inches to 19 inches in height, being 9 inches in diameter at the widest part, and 7 inches in diameter at the top. Each crucible is provided with a lid of the same composition as the crucible; and each crucible must be carefully dried and annealed before use.

Fusion of Steel in the Reverberatory Furnace. The formation of steel by heating together cast-iron and wrought-iron was first suggested by Reaumur.

Siemens in England, and Martin in France, have intro-

duced processes whereby steel of any shade may be obtained at will by melting together wrought-iron and pig-iron in reverberatory furnaces of the regenerative type. If the pig-iron is tolerably free from sulphur and phosphorus, all that is necessary is to dissolve the pig-iron in a bath of wrought-iron at a high temperature. Thus, if 2 cwts. of pig-iron containing 4 per cent of carbon, are added to 6 cwts. of wrought-iron containing 1 per cent of carbon, 8 cwts. of steel of a certain shade of carburization are obtained.

As the atmosphere of the reverberatory furnace in which the steel is formed is an oxidizing one, a partial refining of the metal takes place; the silicon and manganese are oxidized and removed by the slag.

The Siemens-Martin process is conducted as follows:—The pig-iron is first introduced into the reverberatory furnace in a fluid state direct from the blast-furnace. Scrap-iron and scrap-steel are heated to redness and introduced into the furnace together with oxide of iron in the form of rich hematite iron ores. The silicon and manganese which may be present are first oxidized, after which the carbon is attacked. When the carbon is oxidized there is seen a distinct boiling of the molten metal due to the escape of carbonic oxide. The amount of carbon left in the metal is tested by withdrawing a small portion of the metal with a ladle, allowing it to cool, and examining a fractured surface. The oxidation of the carbon is effected by the oxygen gas liberated from the oxide of iron which was introduced; this oxide being itself reduced to metallic iron. If the operation is carried to the extreme limit, that is, if the whole of the carbon is oxidized and removed, a nearly pure malleable iron is obtained. Any oxygen which may be left as oxide in the mass of molten iron is removed by adding ferromanganese, a form of pig-iron containing iron and manganese, but very little carbon. Ferromanganese thus acts as a deoxidizing agent.

If the wrought-iron now obtained has to be converted into steel, a certain amount of spiegeleisen must be added

to it. This compound contains carbon, which it yields up to the iron (thus converting it into steel), and the proportion of spiegeleisen to be added will depend upon the variety of steel which it is desired to obtain.

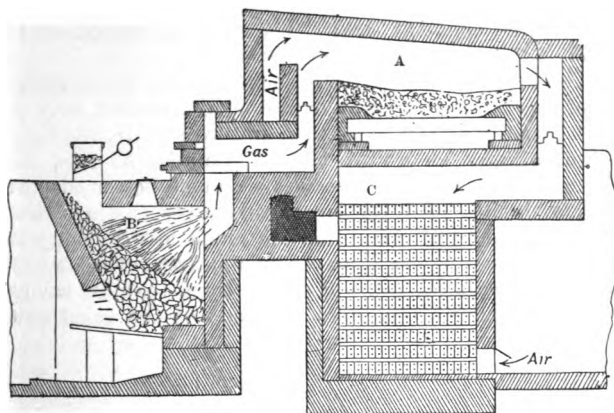


Fig. 43.—Siemens' Open-hearth Furnace with Gas Producer. A, Furnace. B, Gas-producer. C, Chequer brickwork.

The following is a charge worked at the Landore iron and steel works:—

Pig-iron,	...	...	4½ tons.
Scrap-steel,	...	...	15 cwts.
Scrap-iron,	...	...	16 cwts.
Rich iron ore,	...	...	15 cwts.
Ferromanganese,	...	...	8 to 12 per cent.

In Siemens' pig-iron and ore process, 5 tons of pig-iron are treated in one furnace; and after 4 or 5 hours, iron ore is added. This causes the molten mass to boil violently, owing to the oxygen of the ore combining with the carbon contained in the pig-iron and so forming carbonic oxide. More ore is added from time to time, so as to keep up the boiling. Spiegeleisen is then added, and the fluid bath of metal allowed to stand. The heavy metallic iron then separates from the lighter slag, pieces

of limestone being added, if necessary, to increase the fluidity of the slag and so hasten the precipitation of the iron.

When the proper pitch of decarburization of the iron is reached, more spiegeleisen is added in order to produce the desired shade of steel. The metal is tapped out as soon as this spiegeleisen has melted.

The heat of the furnace is such that the liquid metal, after any addition of iron oxide or spiegeleisen, may be kept exactly at the same temperature and in the same state for any length of time. Because of this, the Siemens' and Martin's processes are much better adapted for producing steel for large and heavy castings than the Bessemer process. There is much less difficulty in keeping the contents of 4 or 5 open-hearth reverberatory furnaces ready for pouring at one time, than in having 4 or 5 Bessemer converters all ready at the same time (see fig. 43).

SECTION III.

THE PRECIOUS METALS.

CHAPTER XIII.

GOLD AND ITS ALLOYS: THE ORES OF GOLD, AND THE EXTRACTION OF THE PRECIOUS METAL THEREFROM.

Gold as a Metal. As far back as our history extends this metal has always been highly valued for purposes of ornament and coinage. The reason of this is not far to seek. Gold is a *rare* metal, and the only *yellow* one of which we have any knowledge. It is unacted on by air or by oxygen, and accordingly does not tarnish; whilst even sulphur is without action upon it at any temperature. Gold in this respect markedly differs from the metal silver.

The property, however, by which gold was best known to the early chemists was that it was indifferent to the action of any one acid; being only dissolved by a *mixture* of acids. The mixture generally employed for this purpose is *aqua regia*, a mixture of hydrochloric and nitric acids in the relative proportions of 3 of the former to 1 of the latter. There is, however, one acid *now* known to us which will attack gold, that being selenic acid; and this constitutes the only exception. The Latin name for gold is *Aurum*, whence its chemical symbol, *Au*.

Occurrence of Gold. Gold is one of the most widely distributed of all metals. Though of such wide distribution it is very seldom found in large quantities in any one district. This being so, it is a comparatively rare metal as far as *quantity* is concerned.

"Native" Gold. Gold is almost always found pure or in the native state, occurring usually in the sands of rivers and in alluvial deposits, or in veins of quartz. In

these deposits it is found either in the form of minute grains, or as nodules. These nodules when large are called nuggets; the largest nugget hitherto obtained being the "Welcome" nugget of Ballarat, in Australia, weighing 184 lbs. Besides these sources, gold also occurs contained in many ores such as galena, argentite, and copper pyrites, and these are sometimes worked up for the gold they contain, if it is present in sufficient quantities.

Tellurides of Gold. These minerals contain from 18 to 25 per cent of gold, and from 14 to 26 per cent of silver.

Pure Gold. Gold in a state of absolute purity, or even closely approaching that state, is never met with in commerce, its softness preventing it having any useful applications. Still this absolutely pure gold is required in certain special cases, and is then obtained as follows:—A fairly pure form of native gold (the impurities in which are usually platinum and silver) is taken, and dissolved in the usual solvent, viz. *aqua regia*. This converts the gold into chloride of gold; the impurities it contains accompanying it in a like condition. The acid solution is then evaporated down to complete dryness, and the acids are thus expelled. The residue is now redissolved in a very small amount of water, and a few drops of a strong solution of ammonium chloride added. The platinum in the solution is by this means precipitated, having combined with the ammonium chloride to form an insoluble salt. This precipitate is removed by filtration, and a clear liquid is so obtained, which, when allowed to stand for a week, completely precipitates any silver it contains as silver chloride. The remaining liquid is now a solution of pure gold chloride. Through this solution a stream of sulphur dioxide is allowed to pass; which, being a strong reducing agent, precipitates all the gold in the form of a fine black powder. This powder is collected, washed, and then boiled with hydrochloric acid; again washed with warm water, and finally dried.

After undergoing all these processes the resulting

powder may be said to be "pure gold"; but it still contains about .02 per cent of impurity.

Physical Properties of Gold. The colour of gold is a true yellow. When beaten into thin leaves and viewed by *transmitted* light the metal appears green; but when in a very fine state of division it is dark-red or black.

The ductility and malleability of gold are greater than those of any other known metal. So malleable, indeed, is gold that it is possible to produce gold-leaf (by beating out the metal) which does not exceed the $\frac{1}{252000}$ th of an inch in thickness. And the metal is so ductile, that Faraday calculated that the comparatively small amount of gold contained in four sovereigns could be pulled out into wire long enough to completely surround the earth. Very small quantities of any impurity (especially the metals bismuth and lead), however, sensibly lessen both the malleability and ductility of gold.

The specific gravity of gold is 19.3; its melting point about 1045° C.; and its atomic weight 197.

Gold is a remarkably soft metal, being nearly as soft as lead. Like most of the other metals it is a good conductor of heat and of electricity.

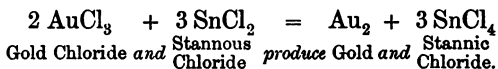
Gold readily combines with other metals to form alloys. When gold is added to glass in the process of glass-making, it confers upon the glass a fine ruby-red colour. Gold crystallizes in the cubic system.

Gold and Chlorine. Gold is at once attacked, especially if in a state of fine division, by moist chlorine gas, with, as a result, the production of auric chloride. This is the trichloride of gold, and it has the chemical formula AuCl_3 . Although moist chlorine so readily attacks gold, it is a curious fact that if the chlorine gas is absolutely dry, as well as the gold, no reaction ensues, no matter how long the two elements are kept in contact with one another.

The gold chloride produced has a deep orange colour, and readily absorbs water from the air (the salt being said to "deliquesce"), crystals having the composition

$\text{AuCl}_3 \cdot 2\text{H}_2\text{O}$ being then produced. Auric chloride is readily soluble in water, in ether, and in alcohol. On the application of heat, this chloride splits up into a mixture of aurous chloride (or gold monochloride, AuCl) and chlorine, if the temperature does not exceed 200°C .; whilst if the temperature rises above that amount it yields up the whole of its combined chlorine, being resolved into metallic gold and free chlorine.

If a solution of this salt of gold is treated with a reducing agent such as ferrous sulphate, stannous chloride, grape-sugar, &c., it is at once reduced; gold in the metallic state being separated, thus:—



The gold thus liberated is in such an exceedingly fine state of division as to require months to settle; whilst the liquid in which the gold is set free has a dark red or purple colour by transmitted light, owing to the presence of minute particles of a compound of gold and tin known as "Purple of Cassius".

Alloys of Gold. Pure gold is much too soft for the various industrial applications to which it is desired to put this metal; so that gold is always *alloyed*, usually with either copper or silver in variable proportions. This addition has the effect of considerably hardening the gold, so making it more durable. The proportion of pure gold in the alloy is expressed by the technical term "carats". Perfectly pure gold is said to be 24 carats "fine". A gold alloy containing 18 carats "fine" would therefore be a mixture of 18 parts of gold and 6 parts of the other metal or metals alloyed with it. Gold is capable of alloying with nearly all the metals, some of which alloys are described below.

Gold-silver Alloys. A large number of these alloys can be obtained by melting gold and silver together in various proportions. The colour of such alloys varies from orange to yellow, and then through greenish-white, until

when an alloy is obtained containing half silver and half gold the colour is almost a pure white. These alloys are mostly used for jewellery.

Gold-copper Alloys. These constitute the most important gold alloys, being extensively used for articles of jewellery and for coinage. Standard gold, or the gold used for British coinage, is 22 carats "fine". It therefore contains 22 parts of gold to 2 parts of copper. In France and the United States 18-carat gold is used for the same purpose. Gold solder is also a gold-copper alloy containing 5 parts of gold to 1 of copper.

These alloys exhibit extreme variations of tint, the colour changing from yellow to reddish when the copper reaches from 30 to 33 per cent in the alloy. An alloy containing 1 part of copper to 8 of gold possesses the maximum degree of hardness.

Gold-mercury Alloys. These rank next in importance as gold alloys, since it is by their aid that gold is in many cases extracted from its ores. Such alloys are readily formed, even in the cold, when gold and mercury are placed in contact with one another; whilst, if the gold be in a fine state of division, and the two metals be heated together, a much richer gold amalgam (as this alloy is called) is formed. With 2 of gold and 1 of mercury, the amalgam is white in colour and pasty in consistency.

Beside the above alloys, alloys of gold with lead, tin, zinc, antimony, &c., can be readily formed. These, however, have no direct uses; since the introduction of these metals into the gold (with the exception of tin) renders the gold *brittle*; and at the same time considerably lessens its ductility.

Classification of Methods for the Extraction of Metallic Gold.

(a) **Dry Methods.** (1) *Washing Processes.*—In these processes the gold is obtained from the sandy and alluvial deposits in which it occurs, by simply washing it in a pan of some sort through which a stream of water is kept constantly flowing. The gold then settles to the bottom in the form of dust owing to its superior specific gravity,

the lighter particles of sand and gravel being washed away. This rude method of extraction is now replaced by—

(2) *Amalgamation Processes*, where the gold in the ore is made to alloy with mercury and so form an amalgam; which amalgam is then retorted, and the mercury thereby driven off.

(b) **Wet Methods.** *Chlorination Processes.*—In these processes the gold in the ore is made to combine with chlorine. The gold chloride thus produced is then dissolved out of the ore by means of water; and the gold in the resulting solution is finally precipitated by the addition of ferrous sulphate.

Amalgamation of Quartz containing Gold. The methods by which gold is extracted from gold-quartz have been largely perfected during the last few years, the larger quantity of gold being now obtained from this source. Indeed, owing to the completeness with which this precious metal can now be obtained, its extraction can be made profitable if a ton of quartz contains but 3 or 4 dwts. of gold.

The first operation which the quartz goes through is that of “breaking”; the quartz being introduced into some kind of rock-breaker and broken down to about the size of a walnut. The quartz in this condition is then either stamped or rolled, and so reduced to a very fine state of division.

By the above means the minute particles of gold present in the quartz have been liberated; and the only thing now to do is by some sort of contrivance or other to catch them; letting the quartz powder, thus deprived of its gold, pass away.

This is done by placing metallic mercury in the stamps or crushers. This mercury amalgamates with, and so picks up, any particles of gold with which it comes in contact. The quartz powder is then carried out of the stamps by means of running water. But the gold has not been entirely picked up by the mercury in the stamps, some of it always escaping along with the powdered quartz. To extract the gold out of the “tailings” (as the stream

of water with the quartz powder in it is called) amalgamated copper plates are used, over which the tailings are made to run. Here any remaining gold is most effectually picked up. At intervals these plates are carefully scraped, and the gold amalgam on them is so obtained. This second amalgam, together with the first amalgam from the stamps, is cleaned by washing in

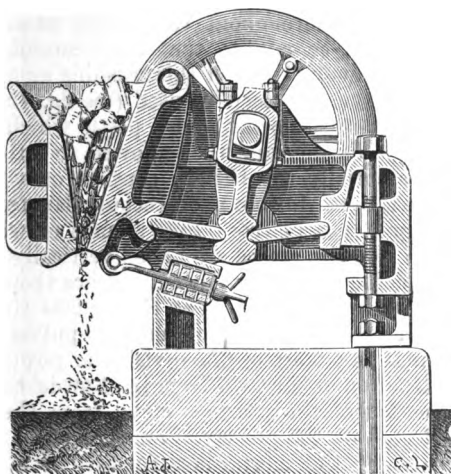


Fig. 44.—Rock Breaker. A, A, Thick iron plates.

water, and is then *pressed* in bags, made either of canvas or chamois leather. This pressure squeezes out the *excess* of mercury in the amalgam; the remaining amalgam is then retorted, and the mercury distilled off, the gold remaining behind.

Apparatus employed for Working Gold-quartz; and Mode of Working.

(1) **Crushing of the Quartz.** This is carried out in two stages. First, the quartz is broken to fragments of a suitable size (about one cubic inch). This is done by means of a “rock-breaker” (see fig. 44), which is usually

the machine called the "Blake Crusher". The form of these breakers, of course, varies; but they may be said to consist essentially of two thick iron plates, AA, fixed somewhat after the fashion of a V, between which the quartz is placed, and then crushed by bringing one plate nearly into contact with the other by means of steam-power.

The next stage is to crush the quartz into the condition of a fine powder. This must be done because the gold is scattered throughout the quartz in small particles, sometimes so minute that they cannot be seen with the naked eye. To effect this crushing an apparatus known as a "stamp battery" is used (see fig. 45). This may be likened to a mortar, and a pestle which is lifted up for a short distance and then allowed to fall into the mortar. Essentially the battery consists of a cast-iron trough, M (the mortar-box), of rectangular form, into which the quartz is placed. Five stamps or weights of some 700 or 800 lbs. apiece are raised vertically upwards about half a foot by steam-power, and are then allowed to drop, sometimes as many as 80 to 200 times in a minute. The result is that the quartz is pulverized, and is so obtained in a state of fine division or powder.

(2) **Extraction of the Gold from the Powdered Quartz.** The extraction of the precious metal from the quartz-dust is effected by the process of amalgamation.

The front of the mortar-box consists of a sieve or screen, S, through which the slime or pulp formed by the stamping of the ore is carried by a stream of water introduced with the quartz into the mortar-box. In front of the screen is an inclined table or trough, T, T,—the "apron"—covered with amalgamated copper plates. As the water carrying the powdered quartz flows slowly down this trough, most of the free gold is seized and retained by the mercury upon the copper plates, forming an amalgam of mercury and gold.

From 60 to 75 per cent of the gold contained in the quartz is caught in this way by the mercury; and at the end of a month the amalgam is scraped off the plates with a blunt chisel.

Nature of the Products obtained from Gold-quartz. The products of the stamp battery consist of (a) finely divided quartz rock, and (b) the minute particles of gold which were scattered throughout it. The quartz rock, however, is not always solely composed of

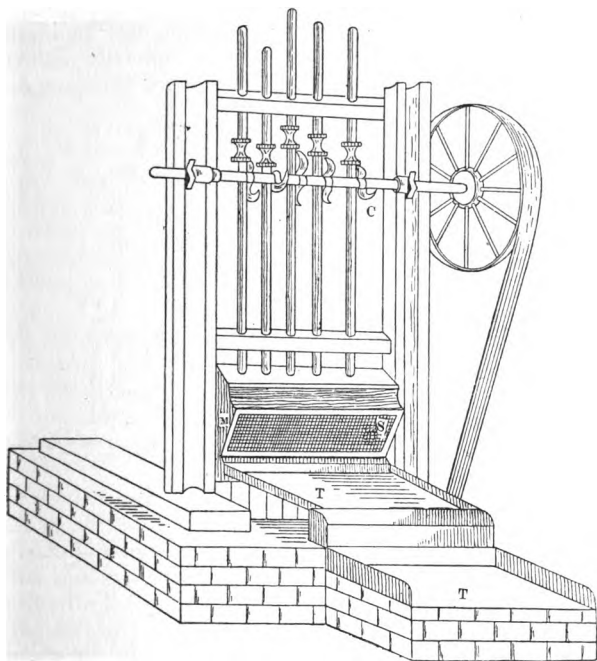


Fig. 45.—Battery of Five Stamps. *m*, Mortar-box. *s*, Screen. *t*, *t*, "Apron" covered with amalgamated copper plates. *c*, Cams for raising the stamps.

quartz; nor are the grains of gold the only metal ever present in it. Thus the quartz not unfrequently contains baryta, talc, or slaty material; but it is the metallic ores which may be present in addition to the gold, which are of most consequence. These ores consist generally of iron and copper pyrites, blende, and galena. These minerals

are themselves frequently rich in gold; and as they are not caught in the amalgamators, special means are taken to extract them from the slime after leaving the amalgamated copper plates. When so caught, they constitute what are termed the "concentrates".

Method of Extracting the Gold from the Amalgam. The gold is extracted from the amalgam simply by distillation; or, as it is technically called, "retorting". The apparatus employed for this purpose

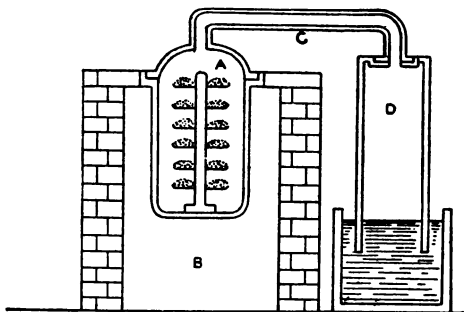


Fig. 46.—A, Iron retort containing the amalgam. B, Furnace. C, Iron tube. D, Condensing chamber and water tank in which to collect the mercury.

is simply a cast-iron retort, A (see fig. 46), from which an iron tube, C, leads off to a chamber or receptacle, D, for condensing the mercury vapour. The amalgam is placed in the retort, the top fitted down, and the contents subjected to a temperature somewhat exceeding the boiling point of mercury (357°C.). The mercury in the amalgam then passes off as vapour, and is condensed in the chamber; whilst the gold is left behind in the retort. If the operations have been properly carried out, it will be found that the loss of mercury per ton of ore treated is about $\frac{1}{2}$ oz. This loss is due to various reasons, the chief of which is that known as "flouring".

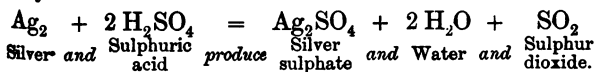
"Parting." The gold obtained from the quartz, sand, &c., with which it was naturally associated, always contains a certain amount of silver, as well as a small propor-

tion of such baser metals as iron, copper, and (more rarely) lead, antimony, bismuth, and tin. The presence of these metals renders the gold brittle, and unfit for the purposes to which it is applied in the arts. The gold is therefore submitted to a process of refining, by which these metals are separated from the bullion. To this operation the term "parting" is applied.

Parting is effected by one of the following methods:—

- (1) By means of sulphuric acid.
- (2) By the action of nitric acid.
- (3) By the use of chlorine.
- (4) Electro "parting".

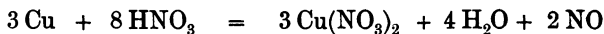
(1) **Parting with Sulphuric Acid.** In "parting" with sulphuric acid, it is requisite first to bring the proportions of silver and copper to gold to a certain standard; the proportions of which are usually 1 of gold to 3 of silver; whilst the copper should not exceed $\frac{1}{20}$ of the gold present. This is done to prevent the gold from screening the silver or copper from the action of the acid, which it would do if the gold present exceeded these limits. Having obtained this standard alloy by adding any constituent that is in deficiency, the next thing to do is to granulate it, so that a larger surface of the metal shall be exposed to the action of the acid. This is done by simply melting the metal and pouring it into cold water. The granulated metal is then placed in a platinum or iron retort together with four times its weight of concentrated sulphuric acid, and is exposed to the action of a strong heat for some two or three hours. The result of this treatment is to convert the silver and the copper present into their respective sulphates; whilst the gold remains unacted upon in the form of a brown powder. Thus the silver sulphate is formed as represented below, whilst the copper sulphate or "blue vitriol" is formed in precisely the same manner:—



The retort and its contents are then allowed to cool,

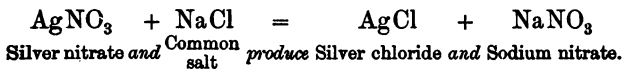
during which time the gold settles down to the bottom. The acid liquid is then carefully decanted or siphoned out of the retort, and the gold washed well with water; the washings being added to the acid solution of the two sulphates. The gold remaining in the vessel after this operation is then removed and melted down. The acid solution, containing the sulphates of silver and of copper, is then treated so as to extract the silver. It is diluted with water and placed in a vessel of lead containing a quantity of scrap copper. On heat being applied the copper takes the place of the silver in its compound, more copper sulphate being accordingly formed and the silver being precipitated. This silver is collected, washed free from acid, &c., and melted in a plumbago crucible with saltpetre and borax. There now remain in the solution only copper sulphate and sulphuric acid. The copper sulphate is obtained in a solid form from the solution by evaporation of the liquid and allowing it to crystallize out. The sulphuric acid left can be concentrated, and then may be used over again for a fresh lot of alloy.

(2) **Parting with Nitric Acid.** In "parting" by the aid of this acid, as with sulphuric acid, an alloy containing about one-quarter of its weight of gold is first produced and then granulated. This alloy is next placed in a retort made of platinum or glass, and heated for some time with strong nitric acid. The gold (as in the previous case) is then left unacted upon, whilst the silver and the copper are converted into their respective nitrates and so pass into solution:—



Copper and Nitric acid produce Copper nitrate and Water and Nitric oxide.

The gold is then melted, cast into ingots, and in this form goes into commerce; whilst the solution is further treated for the silver it contains. The silver in the solution is thrown down in the form of silver chloride by the addition of sodium chloride or common salt, thus:—



This silver chloride is carefully collected and washed quite free of acid, &c., by means of water. The silver present in it is then obtained in the form of a spongy mass by means of the addition of copper or zinc and acidulated water. The spongy silver is now washed free of impurity, and melted so as to obtain it in the compact, well-known metallic form.

(3) **Miller's Process for Refining Gold containing Silver by Chlorine.** This is a process of gold-parting by the aid of chlorine gas, and was first introduced by Mr. Miller, the assayer to the Sydney mint. It is based on the well-known fact that all metals combine more or less vigorously with chlorine, forming the chlorides of those metals. The chlorine, however, does not act on all the metals in an alloy simultaneously; the base metals, copper, iron, zinc, tin, &c., being selected first; then the silver; and last of all the gold. If, therefore, gaseous chlorine be passed through molten bullion the gold is the last thing to be acted upon, all the metals associated with it being converted into chlorides, which are easily got rid of.

Method of working, and Apparatus used. The crucible in which the bullion is placed has to undergo a preliminary operation before it is fit for use. This consists in soaking the crucible, D (which is generally made of earthenware), in a strong borax solution for a few minutes. It

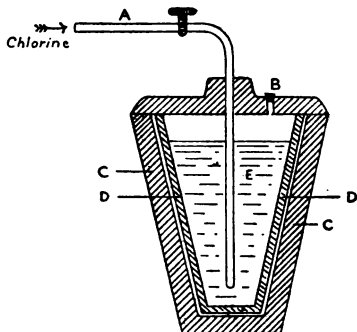


Fig. 47.—A, Clay pipe for conveying chlorine gas. B, Plug fitting into a hole in cover. C, Plumbago crucible. D, Earthenware crucible. E, Molten bullion.

is then taken out and allowed to dry. The object of this soaking is to form a glaze on the inside of the crucible when the crucible is heated. This crucible is then placed inside an ordinary plumbago crucible, C, to which a cover is adapted. This is a precaution taken for fear the earthenware crucible should crack or break on heating. The lid or cover of the plumbago crucible has two holes, through one of which a clay pipe, A (an ordinary tobacco pipe stem is generally employed), passes, whilst the other hole is stopped up with a small plug, B (see fig. 47). The bullion is placed in the inner crucible and melted. The surface of the molten metal, E, is sprinkled over with a little borax, and the cover with its pipe is closely fitted on. The condition of things is then as represented in the diagram.

Chlorine is now led by means of the clay pipe into the crucible, and allowed to bubble through the molten metal. The small quantities of such metals as iron, copper, tin, zinc, antimony, &c., usually present as impurities in the molten mass are at once converted into iron chloride, copper chloride, &c., as the case may be. These chlorides at the temperature of the furnace are volatile, and their fumes are allowed to pass out of the crucible, or are condensed and deposited on the lid or on the inside of the outer crucible. The silver is next attacked by the chlorine, and silver chloride is formed. This silver chloride rises to the top of the liquid metal and forms a fluid scum floating on the surface. It is to prevent the absorption of this scum by the sides of the crucible that the inner surface of the crucible is glazed. While this has been going on the workman has been carefully watching the gases which escape from the vent-hole, and immediately the vapours begin to assume a reddish or brownish appearance (due to the fumes of gold chloride) he knows that all the metals, with the exception of the gold, have been completely acted on, and he at once stops the supply of chlorine.

The earthenware crucible is then taken out and allowed to cool. The gold then solidifies before the scum of horn silver or silver chloride on its surface, which latter

is accordingly run out into moulds. The purified solid gold is lastly extracted from its crucible and washed with a strong solution of salt to remove any silver chloride that may still be adhering to it.

The pure gold thus obtained is in a fit condition to be alloyed with copper for purposes of coinage or for use in the arts.

The silver is then extracted from the silver chloride by replacing it in that compound by copper, zinc, or iron in the well-known way.

The advantages of this chlorination process are many, not the least of which is that the loss of gold is exceedingly small, only about 2 parts to every 10,000 of bullion refined.

(4) **Electro "parting"**. This is a process for separating gold from its alloy with silver and copper by the ordinary method of electrolysis. The metal to be treated is first cast into slabs, which are then suspended in a row in a vat about three feet deep, lined with lead. The slabs are fixed about two or three inches apart, and between them are placed thin plates made of pure copper. There is thus a series of metal slabs alternating with a series of thin copper plates. The vat is then nearly filled with a dilute sulphuric acid solution of copper sulphate, and the series of auriferous slabs is made the "anode" or dissolving pole of a galvanic battery by connecting them up with wires to its zinc or negative pole; the copper plates are similarly made to constitute the "cathode" or receiving pole of the same battery. A strong current of electricity is then passed between the two poles. Copper, being a strongly electrolytic metal, at once begins to be dissolved out of the anode, and is deposited on the copper plates or cathode. After the copper has been extracted from the slabs the gold and silver are left behind in the metallic state. In order to separate these two metals the gold-silver alloy is placed in a cast-iron, or better, in a platinum vessel, and heated with concentrated sulphuric acid. This dissolves all the silver out of the alloy; the gold (being unacted upon) is left behind in a finely divided

condition. The solution is then allowed to cool, and the gold to settle. The acid, containing the silver now dissolved in the form of silver sulphate, is then decanted or siphoned off from the gold. After well washing with hot water the gold is melted and cast, whilst the solution of silver sulphate is treated with common salt. This throws down all the silver as a white curdy precipitate consisting of silver chloride, from which metallic silver is obtained by replacing it with copper or zinc in the ordinary way.

Electro-plating. In "electro-plating" an article with gold, or "electro-gilding" it, we deposit upon it a uniform and more or less thin film of metallic gold. There are many ways of doing this; but the only point in which they differ is in the constitution of the solution or bath in which the articles are placed.

The first thing that is done is to well *clean* the articles to be plated. This may be done by washing them with ordinary washing soda, which very effectually removes any grease which may be upon them; and afterwards rinsing them well with water. The articles are then suspended by means of platinum wire in a vessel made of stoneware, porcelain, or enamelled iron, into which is poured the gilding bath. This bath usually consists of a solution of gold cyanide and potassium cyanide, in the proportions of 1 oz. of gold cyanide to 4 ozs. of potassium cyanide, the whole being dissolved in a gallon of water; though electro-gilders often use widely different baths. Into the bath is then placed the electrode connected with the zinc or negative end of a moderately strong galvanic battery, the articles to be gilded being fitted up to the other end or positive pole of the same battery. The negative electrode, which by this means is made the "anode" or dissolving pole, is a large gold plate. The whole bath is then kept at a temperature of about 60° C., and the electric current passed through it. In this way gold will be dissolved from the negative electrode and deposited upon the articles to be plated. If, however, these objects are made of zinc, lead, tin, or other similar metals, they will not properly "take" or adhere to the

gold. They must in such cases be first covered with a thin film of copper.

CHAPTER XIV.

SILVER AND ITS PROPERTIES: SILVER NITRATE—SILVER CHLORIDE—ALLOYS OF SILVER.

Silver as a Metal. Symbol, *Ag* (*Argentum*). Atomic weight, 108. Native silver occurs in masses and in veins traversing igneous rocks. Mexico and Peru are the countries most productive of this metal.

Pure silver may be prepared by dissolving ordinary standard silver in dilute boiling nitric acid; the solution is then evaporated to dryness, and the mass of metallic nitrates thus obtained is fused to decompose any platinum nitrate which may be present. The fused mass is now dissolved in excess of dilute ammonia, and allowed to stand for 58 hours. The solution is then filtered, and distilled water is added to it. A mixture of ammonium sulphite and cuprous sulphite is then added to the solution, and the whole is thoroughly stirred. On allowing this fluid mixture to stand in a closed bottle for 48 hours, one-third of the silver present is precipitated in the form of minute bright white crystals of silver. If the liquid is now heated to 65° C. nearly the whole of the remaining silver also comes down.

After decanting off the supernatant liquid the crystals of silver are washed with strong ammonia, and afterwards with distilled water. The silver is then melted in a crucible with a little borax and nitre, and poured into a stone mould.

Physical Properties of Silver. Silver possesses a high metallic lustre and has a characteristic white colour, but when rays of light pass through thin silver leaf they emerge blue or bluish-green in colour. With the single exception of gold, silver is the most malleable and

ductile of all metals. When hammered or drawn into wire, silver becomes somewhat brittle, and has to be annealed. When pure it is too soft to use for commercial purposes; it, however, readily alloys with other metals which increase its hardness. Silver has a specific gravity of a little over 10.5, though this may be slightly increased by hammering. Silver crystallizes in the cubic system, and is isomorphous with gold, mixing or alloying with the latter metal in all proportions.

Action of Heat upon Silver. Silver melts at a temperature of 945° C. When the oxy-hydrogen flame is used the silver boils and may be distilled. The silver vapour is of a pale, bluish-purple colour. By condensing this vapour absolutely pure silver can be obtained.

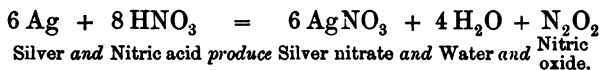
Action of Heat and Air upon Silver. Silver is not appreciably acted upon by pure air even when heated; the tarnishing of silver ornaments when exposed to the atmosphere is due to the presence of traces of sulphuretted hydrogen, which are always present, especially in the atmosphere of towns.

If the molten metal be exposed to air, oxygen is slowly absorbed or occluded by the silver, to the extent of over twenty times its own volume; but this gas is emitted or given off by the metal on cooling. Solidification commences at the surface of the molten silver, and a crust is formed; at the moment when the interior solidifies, the oxygen gas contained in it is liberated, and forces its way through the crust, projecting it into little tree-like elevations. This phenomenon is known as "spitting". This giving off of the occluded oxygen is a sign of the purity of the silver, for if any base metals are present they combine with the oxygen (forming oxides), and so prevent its "spitting".

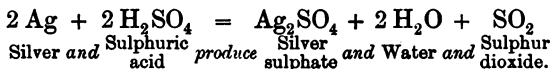
Action of Acids upon Silver. *Hydrochloric acid* has no action upon silver in mass; when powdered or finely divided, the silver decomposes the acid with the formation of silver chloride.

Silver is acted upon by *nitric acid* even in the cold,

with the formation of silver nitrate (AgNO_3) and the evolution of nitric oxide (N_2O_2); the action is accelerated by heat:—



Weak *sulphuric acid* is without action on silver, but the strong acid dissolves it, silver sulphate (Ag_2SO_4) being produced, and sulphur-dioxide (SO_2) liberated—



Silver and Oxygen. Silver combines but slowly with oxygen, the spontaneous oxidation of silver in air at the ordinary temperature being almost inappreciable; the combination of the two elements may, however, be indirectly effected. Three oxides of silver are known—(1) Argentous oxide (Ag_4O), in which the molecule is composed of 4 atoms of silver and 1 of oxygen; (2) Argentic monoxide (Ag_2O), 2 atoms of silver being combined with one of oxygen; and (3) Argentic dioxide (Ag_2O_2), 2 atoms of silver combining with 2 atoms of oxygen to form the molecule.

Argentous Oxide (Ag_4O) is a black powder which may be prepared by passing a current of hydrogen through a tube containing heated oxalate or citrate of silver.

Argentic Monoxide (Ag_2O) is produced when carbonate of silver is heated; it is also precipitated when potassium hydrate solution is added to a solution of silver nitrate. It is a brownish-black powder which readily parts with its oxygen on heating.

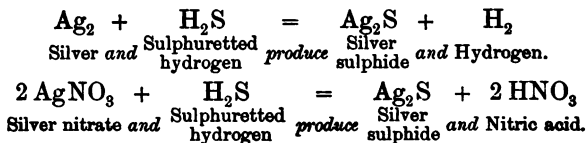
Argentic Dioxide (Ag_2O_2) may be prepared by decomposing a concentrated solution of silver nitrate by means of a current of electricity (the decomposition thus effected being known as electrolysis); black crystals of argentic dioxide then gradually form on the positive pole. The usual way of preparing this oxide, however, is by the action of heat upon solid silver nitrate.

Physical and Chemical Properties of Sulphide of Silver. Silver Sulphide (Ag_2S) occurs native as *Argentite* or Silver Glance, a mineral which crystallizes in the cubic system; it contains 87 per cent of silver combined with 13 per cent of sulphur. This compound has a metallic lustre, lead-gray colour, and is very malleable. Silver sulphide readily melts; and when heated with carbon in the presence of air it decomposes, sulphur dioxide being liberated and metallic silver left behind.

Chlorine, or strong hydrochloric acid, attacks silver sulphide with the production of silver chloride. Nitric acid readily decomposes sulphide of silver, with the separation of sulphur. On passing a current of hydrogen gas over silver sulphide at a temperature of 440°C ., tendril-like strings of metallic silver are obtained.

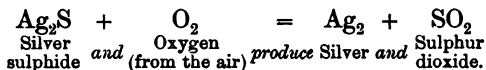
Modes of Formation of Silver Sulphide. If finely divided silver and sulphur be mixed together and heated, direct combination between the two elements takes place at a red heat.

Sulphuretted hydrogen attacks silver with the formation of the sulphide; the same compound is also produced when sulphuretted hydrogen gas is passed into solutions of silver salts:—



Action of Heat upon Sulphide of Silver. The affinity of the silver and the sulphur for one another in this compound (Ag_2S) is so strong that heat alone is not able to decompose it; but in trying the experiment care must be taken to exclude air or oxygen.

Action of Heat and Air upon Sulphide of Silver. When strongly heated sulphide of silver has a current of air passed over it, it is decomposed into silver and sulphur dioxide:—



Combination of Silver Sulphide with other Sulphides. Silver sulphide is found in nature in combination with other sulphides. These double sulphides frequently constitute well-defined and valuable minerals. *Stephanite* is an iron-black metallic-looking mineral, consisting of a double sulphide of antimony and silver. It contains 68·36 per cent of silver. *Pyrargyrite* is a dark-red mineral composed of the sulphides of antimony and silver, and when pure contains 59·78 per cent of silver. *Proustite* is a combination of the sulphides of silver and arsenic. This double sulphide contains 65·45 per cent of silver, and possesses a very brilliant lustre and a light-red colour.

Sulphide of silver combines also with the sulphides of copper, iron, arsenic, and lead.

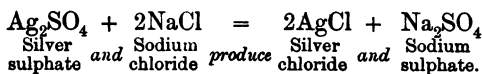
Sulphate of Silver: its Physical and Chemical Properties. Silver sulphate (Ag_2SO_4) is a colourless, crystalline, anhydrous salt, sparingly soluble in water, easily soluble in ammonia. This salt when in solution is decomposed by copper, silver being deposited and copper sulphate being formed.

Mode of producing Sulphate of Silver. Silver sulphate is produced when silver is boiled in concentrated sulphuric acid; it is also formed on the addition of sulphuric acid to a strong solution of silver nitrate. And when silver sulphide is roasted in contact with air at a low red heat, it is easily converted into silver sulphate.

Action of Heat upon Sulphate of Silver. Silver sulphate is decomposed when strongly heated, sulphur dioxide and oxygen being liberated, and metallic silver being left behind. If mixed with carbon, the silver sulphate is decomposed at a red heat.

Action of Chloride of Sodium upon Sulphate of Silver. When an intimate mixture of chloride of sodium and silver sulphate is heated, the two salts react

upon one another, silver chloride and sodium sulphate being formed:—



Silver Nitrate: its Physical and Chemical Properties. Silver nitrate (commonly called *lunar caustic*) is a colourless anhydrous salt, crystallizing in flat tables. It attacks and rapidly destroys organic substances, and stains the skin black.

It is generally prepared by the action of nitric acid upon silver:



Action of Heat upon Silver Nitrate. When heated to a temperature of about 224° C., silver nitrate melts without decomposition.

Method of Separation of Nitrate of Silver from Nitrate of Copper. The silver of commerce usually contains a little copper. These two metals dissolve in nitric acid, forming nitrates, the copper nitrate colouring the solution green.

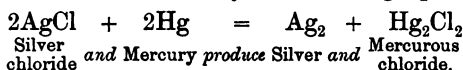
To separate this impurity from the silver nitrate, hydrochloric acid is added to the solution, which precipitates the silver as chloride; the copper chloride being soluble, remains in solution. The silver chloride is then filtered off and well washed, first with a weak solution of hydrochloric acid, and then with water; it is now boiled with a solution of potassium hydrate, by which it is converted into argentous oxide; lastly, on heating this oxide with nitric acid, pure silver nitrate is formed.

Silver and Chlorine. Silver combines with chlorine at ordinary temperatures, forming silver chloride (AgCl).

Two chlorides of silver are known, only one of which, argentic chloride, is of importance. The nature of the other chloride is not well known; its formula is said to be Ag_2Cl .

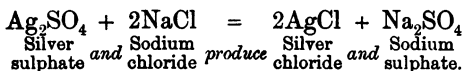
Chloride of Silver: Physical and Chemical Properties. Silver chloride (AgCl) occurs in nature as the mineral called *horn silver*; it is almost insoluble in water, but readily soluble in solutions of ammonia, of common salt, and of potassium cyanide. At about 260°C . it melts to a yellow liquid, which forms a resinous mass on cooling. Sp. gr. = $5\frac{1}{2}$; malleable, sectile, with waxy lustre.

Silver chloride is an extremely stable compound, and is formed when other silver compounds (or even metallic silver) are mixed with common salt and heated in contact with air. Silver chloride is decomposed by metallic mercury, even at ordinary temperatures; the reaction which ensues is illustrated by the following equation:—



Under ordinary conditions silver chloride rapidly changes colour (from white to black) when exposed to white light. For this reason it is very largely used in photographic printing processes.

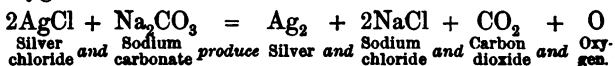
Methods of Formation of Silver Chloride by Dry and by Wet Processes. (a) **Dry Method.** Silver chloride is formed when a mixture of silver sulphate and sodium chloride is heated:—



(b) **Wet Method.** Silver chloride is precipitated in white curdy masses when hydrochloric acid is added to a solution of silver nitrate. Articles of silver which have been buried in the earth for a long time become covered with silver chloride, which forms slowly, and often cements shells, stones, &c., to the articles.

Method of Reduction of Silver Chloride by Carbonate of Soda. When carbonate of soda is mixed with silver chloride and the mixture fused, reduction takes place, metallic silver being produced. The

other products are sodium chloride, carbon dioxide, and oxygen.

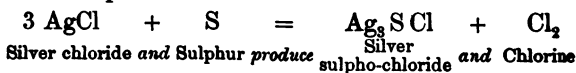


Method of Reduction of Silver Chloride by Zinc. Zinc (or iron) in the presence of water reduces silver chloride to silver; the action is accelerated by acidification, and by the injection of steam.

Action of Acids upon Chloride of Silver. Silver chloride is practically insoluble in either nitric, sulphuric, or dilute hydrochloric acids; it is, however, more soluble in *strong* hydrochloric acid.

Action of Chloride of Sodium upon Chloride of Silver. Silver chloride is insoluble in water, but is readily soluble in a solution of common salt or sodium chloride, owing to the formation of a soluble salt—a double chloride of silver and sodium. This fact is taken advantage of in the extraction of silver from its ores, the process in which it is used being known as Augustin's Process. Here the silver in the ore is converted into silver chloride, which is then obtained in the form of a solution by the action of a solution of sodium chloride. From this the silver is obtained by placing in the liquid strips, or a plate, of metallic copper, upon which the silver is then deposited.

Action of Sulphur upon Chloride of Silver. When sulphur and silver chloride are heated together, a soft blackish substance having a somewhat metallic lustre is produced. The exact nature of this substance is not yet definitely understood. It is, however, thought to be a chemical compound composed of silver, chlorine, and sulphur; and accordingly the name silver sulpho-chloride is applied to it. It is clear that in order to have produced this compound the sulphur must have first decomposed the silver chloride thus:—



The chlorine so liberated is not given off as such, but at once attacks the excess of molten sulphur present, forming a chloride of sulphur (S_2Cl_2). The use to which silver sulpho-chloride is applied in the arts is for the purpose of staining glass yellow for ecclesiastical art work in windows, &c.

Action of Metallic Sulphides upon Chloride of Silver. Certain metallic sulphides, such as lead sulphide, when heated with silver chloride melt with it to form fusible substances.

Action of Protoxide of Lead upon Chloride of Silver. When silver chloride and litharge (PbO) are fused together, the silver chloride dissolves in the molten litharge, forming a mixture or an alloy of litharge and silver chloride; this mixing takes place in all proportions.

Alloys of Silver. (a) **Silver-copper Alloys.** The alloys of silver with copper are almost the only important alloys of silver from a commercial point of view. If the percentage of copper in the alloy is less than 50, the resulting alloy is white; whilst if the percentage of copper to silver rises above this amount, the alloy assumes a reddish tint. By alloying silver with copper, the hardness and elasticity of the silver are increased; but at the same time the ductility of the metal is diminished. The most important alloy composed of silver and copper is that used for the British coinage. This contains $92\frac{1}{2}$ parts of silver and $7\frac{1}{2}$ parts of copper in every 100 parts of alloy.

Besides this alloy, there are the alloys called "silver solders". These contain silver and copper, together with a little brass; sometimes they include a little bronze and arsenic as well.

(b) **Silver-lead Alloys.** These have no very great commercial uses. By the addition of lead the malleability of the silver is lessened. Besides this, these alloys exhibit a tendency to liquefy; so that if the alloy is fused and then allowed to cool, instead of a homo-

geneous alloy being obtained a number of silver-lead alloys are formed, owing to the separation of the alloy into layers differing in density, fusibility, &c.

(c) **Silver-zinc Alloys.** At a temperature much above the melting point of zinc, silver readily combines with that metal; forming a number of alloys, all of which are of a much whiter colour than the zinc alone.

(d) **Silver-mercury Alloy.** Silver is readily dissolved by mercury, forming an alloy known as "silver amalgam". On getting rid of the excess of mercury in the amalgam by squeezing it in a canvas bag, a soft white alloy is obtained. The fact that silver so readily alloys with mercury is taken advantage of in the extraction of silver from its ores. (See amalgamation process, p.).

(e) **Silver-gold Alloys.** Besides the above alloys, certain alloys of silver and gold can be obtained which are of theoretical interest only.

Silver-palladium Alloys. An alloy of 33 parts of silver with 67 parts of palladium is very homogeneous. Such an alloy absorbs the same volume of hydrogen gas that pure palladium does. Palladium alloys with silver in all proportions.

CHAPTER XV.

THE ORES OF SILVER: WITH SOME METHODS FOR THE EXTRACTION OF THE PRECIOUS METAL THEREFROM.

Ores of Silver. The ores of silver rarely occur in a pure or unmixed condition; they are usually found finely disseminated amongst or mingled with other ores. Silver ores may be conveniently divided into two classes:—

- 1) Accessory ores.
- (2) Special ores.

Accessory Ores of Silver contain other metals, or at least one other metal, in addition to silver; and these

ores are usually purchased with a view to the extraction of these other metals; the extraction of the silver being of secondary consideration.

These accessory ores are divided into:—

(a) Plumbiferous ores or galenas, containing more than 20 per cent of silver.

(b) Copper minerals, containing more than 1 per cent of copper, but not very argentiferous; the proportion of silver being about 5 parts in 10,000 parts of the ore.

(c) Zinciferous ores, as blende; containing 25 to 30 per cent of zinc, and from 10 to 20 parts of silver in 10,000 parts of the ore.

(d) Ores in which sulphur is the main constituent, as argentiferous pyrites.

Special Ores of Silver. These are ores which are treated for their silver alone. The following are the chief special ores of silver:—

(a) *Native Silver*: this occurs in platy and fibrous masses in the old rocks of the earth's crust.

(b) *Horn Silver*, or silver chloride, Ag Cl , contains 75·3 per cent of silver, and 24·7 per cent of chlorine. It occurs chiefly in Mexico, Chili, and Peru. In horn silver the chlorine is often partly replaced by bromine and iodine; when we have bromide and iodide of silver as well as the chloride.

(c) *Silver Glance*, or silver sulphide, Ag_2S . This important ore of silver contains 87·1 per cent of silver, and 12·9 per cent of sulphur, when pure. It commonly occurs mixed with galena, pyrites, and sulphides of antimony. It occurs in Norway, and at Freiberg in Germany; and is also abundant in Mexico, Peru, and California.

(d) *Proustite*, or light-red ruby silver ore, $3 \text{Ag}_2\text{S} \cdot \text{As}_2\text{S}_3$, contains 65·45 per cent of silver. It is the most highly lustrous of known minerals, the finest specimens having been obtained from Chañarcillo in Chili.

(e) *Pyrargyrite*, or dark-red ruby silver ore, $3 \text{Ag}_2\text{S} \cdot \text{Sb}_2\text{S}_3$, contains 59·78 per cent of silver, together with antimony and sulphur. It is usually associated with other

silver ores, and has been found in Cornwall; the chief localities, however, are Colorado, Chili, and Freiberg.

(f) *Telluride of Silver*, Ag_2Te , contains 62.8 per cent of silver. This ore was discovered in Colorado in 1873.

(g) *Fahlerz*; this is a very complex ore of silver found at Freiberg, and also in Norway, Colorado, &c.

General Classification of Methods for the Extraction of Silver from its Ores.

- | | |
|---|--|
| I. Amalgamation Processes. | { Mexican Patio Process.
Barrel Process.
"Pan" Amalgamation Process. |
| II. "Lead" Processes. | { Pattinson Process.
Parkes's Process. |
| III. Processes where the ore is smelted with lead or copper ores. | |
| <i>The above are all known as "dry" processes.</i> | |
| IV. Wet Processes. | { Ziervogel's Method.
Augustin's Process.
Russell's Lixiviation Process; &c. |

Extraction of Silver from Argentiferous Copper. The method chiefly employed for extracting silver from argentiferous copper is the "electrolytic process". Briefly, this process is as follows:—The argentiferous copper is first cast into the form of slabs, copper hooks being inserted into the slabs whilst the metal is still molten in order to suspend them by. These slabs are then hung in rows in a vat some 4 feet wide and $3\frac{1}{2}$ feet deep, constructed of wood lined with sheet-lead.

Opposite each copper slab is suspended a pure copper plate. The vat is then nearly filled with a dilute sulphuric acid solution of copper sulphate.

The copper slabs and the plates are then placed in connection with a battery or some other source of electricity, and are so connected up that the current first enters the series of argentiferous copper slabs, then passes through the copper sulphate solution to the plates, finally

passing out of the vat along the wires in connection with the pure copper plates. That is to say, the copper slabs are made the "anodes", and the copper plates the "cathodes" of an electric battery.

The following diagram (fig. 48) represents the arrangement in the simplest possible form:—On passing the electric current the copper with the silver it contains will be dissolved off the slab or anode, A (see fig. 48). Of these two metals the copper only passes through the solution, and is finally deposited in a very pure state on the plate or cathode, B. The silver is practically insoluble in the dilute sulphuric acid of the bath, and it falls to the bottom of the vat in the form of a fine mud, D. This mud is collected at the end of the process and cast into ingots.

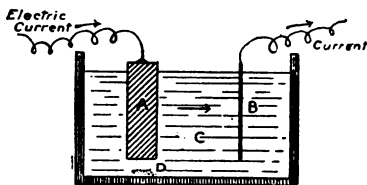


Fig. 48.—A, Slab of argentiferous copper. B, Pure copper plate. C, Dilute sulphuric acid solution of copper sulphate. D, Fine silver mud.

Liquation Process for Extraction of Silver.

This is a process for separating silver from argentiferous copper by the aid of molten lead. The lead dissolves the silver out of the copper, forming a lead-silver alloy. This alloy is then separated from the copper by liquation, and the silver is finally obtained from the alloy by cupellation.

This liquation process was at one time in very extensive use in Europe. At the present time, owing to the perfection to which the wet methods for extracting silver have been brought, the liquation process has fallen into disuse; and it is doubtful if it is now anywhere put into operation, except perhaps in the Hartz, and in Japan. Not only is this so, but it is impossible to completely liquate out of the copper all the lead that is introduced into it in this process, some 30 per cent of lead and a proportional amount of silver always remaining. The copper has therefore to be subjected to a further refining

process before it is obtained in a commercially pure state. This fact, taken into account with the consideration that the lead alloy has to be cupelled and that the process requires most careful watching and regulation of temperature, makes the cost of this liquation process necessarily great. It has therefore been abandoned for cheaper, but nevertheless more perfect methods.

Description of Furnace for Liquation Process.

The liquation furnace in itself is exceedingly simple in

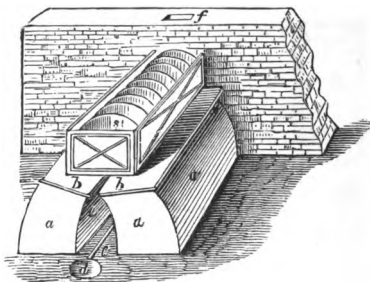


Fig. 49.—Liquation Hearth employed in the Hartz. *a, a*, Parallel semi-arches. *b, b*, Inclined tops of semi-arches. *c*, Central gutter. *d*, Circular pit. *f*, Chimney. *s, s*, slabs.

construction, consisting merely of two parallel semi-arches, *a a*, or walls of brick or stone work which incline towards a median line. The passage below these two walls communicates at the back with a chimney, *f* (see fig. 49).

A space of 2 or 3 inches is left between the upper part

of the two walls, or two halves of the liquation hearth (as this part of the furnace is called), for the liquated metal to pass through. The floor is made sloping towards the median line, and also from the back of the furnace to the front. This floor receives the drops of metal as they liquate out; and owing to its construction, these drops all tend to run towards the central line of the floor, which is scooped out so as to form a gutter, *c*. This gutter runs into a circular pit, *d*, in which the liquated metal of course collects. On the hearth of the furnace the crude metal (which is cast in the form of circular slabs) is placed, the slabs standing in an upright and transverse position some six inches apart. The empty spaces between these slabs are then filled with charcoal, the whole being packed in between two upright iron

plates which run the whole length of the hearth. The furnace is then lighted, charcoal being the fuel used. This lighting is effected by placing live charcoal on the top of the slabs, and also into the passage between the two walls. When this fuel burns away the supply is renewed as may be necessary, till the liquation is completed.

Mode of Operation in Liquation Process. In working the liquation process at least three distinct operations have to be carried out. These are:—

- (1) Preparation of an alloy of copper, silver, and lead.
- (2) Liquation of this alloy.
- (3) Treatment of the residual copper and the liquated lead.

Besides these, a separation operation has to be performed if the accessory products, &c., are to be treated.

(1) The argentiferous copper, which is generally unrefined or black copper, is first melted in a kind of small blast-furnace, and an amount of lead equal to about 11 times the weight of silver in the alloy is added. This ensures an excess of lead in the alloy. The molten metal is then cast in the form of a round cake or slab about 2 feet in diameter and 3 inches thick. This usually absorbs all the metal obtained by one smelting, and the weight of such a slab may be some 300 to 400 lbs.

(2) These metal cakes are then placed on the liquation hearth in the manner before described. The floor of the furnace is then warmed by placing live charcoal into the passage so that the liquated metal shall not solidify before it reaches the basin. The furnace is then lighted, and the temperature kept below the melting point of copper, but above that of lead. The greater part of lead (alloyed with nearly all the silver in the argentiferous copper) then liquates or flows out, and a lead-silver alloy is so obtained. The temperature is adjusted so that the cakes sink as they melt at an equal rate, by doing which the maximum amount of liquation takes place.

The liquated lead is then submitted to the process of cupellation, and the silver present in it is so obtained.

(3) The copper, which still retains some 30 per cent of lead, with of course a proportionate amount of alloyed silver, is then submitted to a second liquation at a higher temperature on the sloping hearth of a reverberatory furnace. Owing to the furnace conditions and to the high temperature employed, the lead (as fast as it flows out) is converted into litharge; whilst in association with this is a quantity of copper oxide. This copper residue is usually melted up with a fresh lot of argentiferous copper.

Finally, the copper left from this second liquation undergoes refining, when it is obtained in a commercially pure state.

Nature of the Products in the Liquation Process. The lead liquated out of the copper cakes is lead-like in appearance, but owing to the included copper and silver it is rather hard. The copper which remains on the liquation hearth is very brittle and somewhat slaggy in appearance; whilst pieces of charcoal are not infrequently found in it. The metal itself contains not only copper, but a considerable amount of lead, and a proportional quantity of silver. It has therefore to be further treated to what amounts to a second liquation at a higher temperature. The remaining lead is then separated from the copper, and owing to its high temperature and the presence of air at once assumes the form of litharge; whilst at the same time a portion of the copper is oxidized and comes out with the lead.

Extraction of Silver from the Ore. A large number of processes are employed in the extraction of silver from its ores. Different means have to be used where the ores treated are different; thus, the ores may differ in composition and in richness, and a method of extraction suitable for poor ores would be wasteful if used for rich ones.

In some silver-producing countries fuel is dear and labour is cheap, consequently methods are adopted for the extraction of silver differing widely from those used in other countries where the conditions are perhaps just the contrary.

All the processes used for extracting silver fall into three classes:—

(1) The method of fusion with lead.

(2) Amalgamation method.

(3) Wet methods.

(1) **The Method of Fusion with Lead.** This is the most ancient of the three methods, and only rich ores are now thus treated. The ore is fused with lead, which is then removed by cupellation.

(2) **Amalgamation Method.** In this method the silver is caused to alloy with mercury; and the mercury, being volatile at a moderately high temperature, is then removed by distillation. The components of this class are:—

(a) *The Mexican or Patio Process* (see p. 150).

(b) *The European Process.* In this process the amalgamation is brought about in barrels revolving on a horizontal axis.

(c) *The American Process*, in which the alloying with mercury takes place in iron pans.

(3) **Wet Methods.** In the wet methods the silver ores are so treated as to convert the silver into a salt soluble in one or other of certain liquids. The silver is then precipitated from its solution by the use of copper, zinc, or scrap-iron. The following processes belong to this class:—

(a) *Von Paterna Process.* Chloride of silver is formed by roasting the ore along with common salt; the silver chloride so produced is dissolved in sodium thiosulphate; sodium sulphide is then added, which causes the production of silver sulphide. This latter compound is first oxidized and then decomposed when strongly heated, metallic silver being finally produced.

(b) *Ziervogel's Process.* The ore is treated so as to produce silver sulphate; this compound is then extracted by hot water containing sulphuric acid; copper is then added, which causes the deposition of the silver (see p. 155).

(c) *Augustin's Process.* The silver is converted into chloride by roasting with common salt. Silver chloride

forms a soluble double chloride with common salt, and from the solution of this compound the silver is extracted by the use of metallic copper (see p. 159).

Mexican or "Patio" Amalgamation Process for the Extraction of Silver. The Mexican or Patio amalgamation process was invented by Bartholome Medina of Mexico in 1557. Since his time the method has undergone but little alteration. Its suitability depends upon the scarcity of fuel, the cheapness of labour, and the poverty of the ore.

Apparatus employed in the Patio Process. The apparatus employed in the "Patio" process is simple in its nature and construction, consisting of:—

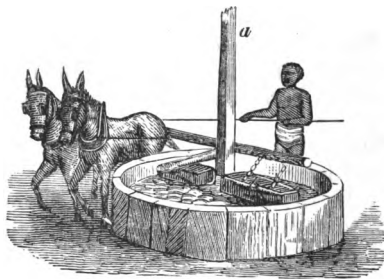


Fig. 50.—Arrastra or Mexican Grinding Apparatus.
a, Pivoted wooden pillar.

1. **Hammers**, which are used for breaking up the ore; after which it is crushed under—

2. **Stamps**, these consisting of wooden rods shod with iron, which are raised by cams attached to a hori-

zontal axis, and then allowed to fall upon the ore which is placed beneath. The stamped ore is now ground to a fine powder in the—

3. **Arrastras or mills.** These are circular stone pavements 12 feet in diameter, made of well-dressed stones (usually porphyry) weighing from 300 to 400 lbs. each, the crevices between being filled up with cement (see fig. 50). The sides of the arrastras are made of the same material. In the centre of each mill is a vertical pivoted wooden pillar, *a*, projecting from which are two radial arms for the suspension of the grinding stones. The mules which work the mill are harnessed to the ends of these arms. The powdered ore is conveyed from the mills in—

4. **Casks** to a—

5. **Trough**, where the ore is spread out, and from which it is carried to—

6. **The Floor or "Patio"**, from which the process takes its name, and which is the spot where the amalgamation of the silver is effected (see fig. 51). This "Patio" is usually a large court-yard paved with flagstones cemented



Fig. 51.—The Patio.

together, the average Patio covering an acre and a half of ground. From the Patio the ore is conveyed to—

7. **The Washing Tanks or Vats**, which are also constructed of porphyry, and in the centre of which is a vertical pivoted post with horizontal arms and vanes, which stir up the water when they are set in motion by mules or horses.

The silver amalgam from these washing tanks is first placed into—

8. **Conical bags** of leather and canvas, and the excess of mercury squeezed out, after which the pasty amalgam remaining is finally treated in—

9. **Mercury bottles** or cast-iron retorts, where the mercury is distilled off, leaving a spongy mass of silver behind.

Materials used in the Patio Process. The

silver usually exists in the ore as silver sulphide, and the materials employed for extracting the silver are—

(1) **Magistral**, or copper sulphate. This is prepared from copper pyrites containing about 10 per cent of copper. The pyrites is reduced to the condition of fine powder, dried, and exposed to the air for some months, during which time it undergoes oxidation. It is then calcined in a double-bedded furnace, and the copper is thus completely converted into copper sulphate. Crystallized copper sulphate answers the same purpose as the magistral, and is now largely imported.

(2) **Common Salt**. This is obtained from the sea-coast or from salt lagoons. The purest product contains 95 per cent of sodium chloride.

(3) **Mercury**. Cinnabar (mercuric sulphide) is very rare in Mexico, and all the mercury used is imported.

Method of Working in the Patio Process. The ore is first broken into lumps with hammers, and then put through the “stamps” and reduced to the size of coarse gravel. It is now ground to a fine powder in the arrastra. The finely powdered ore is next transported in casks to a large trough or tank, where about 60 tons of ore are spread out to a depth of a few inches; and here it is stored till required for use in the next process.

The ore is afterwards subjected to amalgamation in the “Patio”. It is made into circular heaps one foot in thickness, and common salt, magistral, and mercury are successively added to it. For every 1000 lbs. of silver, 30 tons of salt, 3 tons of magistral, and 18,000 lbs. of mercury are used. The first stage is called the “salting”, when 6·4 per cent of salt is added, together with a little water, the salt being well mixed with the ore by being trodden in circles by six horses abreast. The mass is then turned over and assayed to determine the percentage of silver present in it. The next day magistral and mercury are added according to the result of the assay. If there be, for example, 64 ozs. of silver to the ton, then 0·2 per cent of magistral is first added to the ore, and this is afterwards well trodden in by horses.

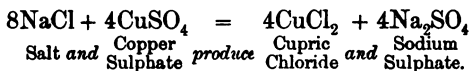
The mass within the "Patio" now becomes spongy and dark-coloured, and mercury is sprinkled over it from linen bags, 1440 lbs. of mercury being added for every 60 tons of ore. Only two-thirds of the mercury is added at first, the remainder being sprinkled over at intervals subsequently. An average sample of the whole mass is now taken, and the amount of amalgam present is determined. Fresh magistral and mercury are added at intervals, and the mass is then again trodden over by horses.

The mass of ore is now in the form of a low heap or "torta", and is ready to receive the last portion of mercury, which is added to dissolve out the silver amalgam which has been formed. In order to effect this, 420 lbs. of mercury are added for every 60 tons of ore treated. The tramped argentiferous mud is then removed from the "Patio", and is washed in vats made of porphyry, 60 tons of mud being washed in 20 hours. From the vats the amalgam, containing 8 parts of mercury to 1 part of silver, is removed, and after undergoing a process of "squeezing" is treated directly for its silver, as described below.

On warm, bright days the yield of silver is greater than on cold, cloudy days, but the loss of silver under the best conditions is about 25 per cent.

Nature of the Products in the Patio Process. The silver amalgam obtained by the "Patio" process contains 8 parts of mercury to 1 part of silver, and the loss of mercury during the operation is nearly equal to the weight of the silver extracted. Any native gold or silver which may be present are removed by adding mercury to the ore while it is being ground to a powder in the "arrastra".

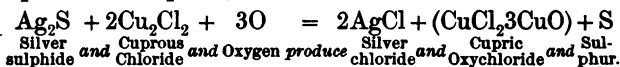
A great many intermediate products are formed on the addition of the salt, the magistral, and the mercury to the ore. The reactions which ensue are complicated, and are as follows. The copper sulphate is first converted into cupric chloride by the action of the common salt, thus:—



By the action of this cupric chloride in the presence of air, the silver sulphide is changed into silver chloride, thus:—



The cuprous chloride in the presence of air also acts upon silver sulphide, thus:—



The silver is now entirely in the form of chloride, and on the addition of mercury the chloride is decomposed, thus:—

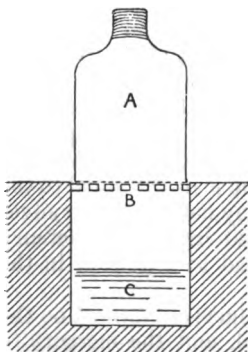
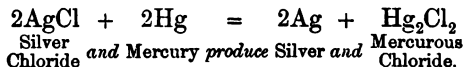


Fig. 52.—Mercury Bottle Retort.

The silver so liberated at once forms an amalgam with the excess of mercury present.

Working of the Amalgam produced in the Patio Process. The silver amalgam is placed in conical bags; the upper part of which consists of leather, the lower part being made of closely-woven canvas. On squeezing the bags, the excess of mercury passes out through the pores of the canvas, leaving an amalgam containing 4 or 5 parts of mercury to 1 part of silver.

This amalgam is broken up and treated as follows:—The bottom is knocked out of an iron “mercury bottle”,

A, the top is plugged up, and the bottle is filled with the pasty silver amalgam (see fig. 52). The bottle is now placed over an iron plate, B, which is pierced with circular holes; underneath this plate is a receptacle containing water, C, into which the mercury drops as the heat parts it from the silver. A fire is very carefully built up around the bottle to heat the amalgam to the right degree; for if the temperature be too low, the whole amalgam flows down, if too high the silver melts.

In California this rude apparatus has been replaced by cast-iron retorts, with much better results.

CHAPTER XVI.

ORES OF SILVER AND METHODS OF EXTRACTION OF THE METAL (CONTINUED).

Extraction of Silver from Argentiferous Regulus: Ziervogel's Process. *Regulus*, otherwise known as matt or coarse metal, is the first product obtained in the smelting of copper ores. This regulus not unfrequently contains a notable amount of silver—some 0.1 to 0.3 per cent—which is capable of being profitably extracted by Ziervogel's process. For the proper working of this process it is not essential that the amount of silver in the ore should be very great; indeed in this method, as in the other wet methods for silver extraction, it is preferable that the ores should not be too rich in silver. Thus, in the case of the Mansfield ore, with which this process was first worked, the amount of silver (in the form of silver sulphide) does not rise to more than 0.5 per cent.

The "regulus" consists essentially of iron, copper, and silver, all in the form of sulphides. This regulus is first of all crushed, and then roasted at a low temperature in stalls in order to drive off as much sulphur, arsenic, and antimony as possible. The ore is then allowed to cool;

and is again and this time more finely crushed; it is then roasted for a period of about an hour and a half at a low temperature. During this period of gentle heating the iron sulphide combines with oxygen (from the air) and is thus converted into iron sulphate. A similar period of roasting at a somewhat higher temperature similarly brings about the conversion of the copper sulphide to copper sulphate. The temperature is again raised for an hour and a half or so (during which time the mass is thoroughly stirred), when finally the silver sulphide is brought into the state of silver sulphate.

The next thing that is done is to bring about the decomposition of the iron and copper sulphates, while leaving the silver sulphate intact or unaltered. This is accomplished by raising the temperature of the furnace; and it is at this stage in the process that the very greatest care has to be taken, a considerable amount of skill and experience being required to know exactly the time when the roasting mass should be raked out so as to avoid the decomposition and consequent loss of the silver sulphate.

The roasted mass now contains copper oxide and iron oxide, together with silver sulphate. Of these three substances, the last is the only one soluble in water. It can therefore be obtained by submitting the roasted mass to the process of lixiviation. To do this the roasted ore is placed in a series of vats (see fig. 53) having false bottoms, the spaces between the false and the true bottoms of the vats being filled with some filtering material, such as tow, &c. About five cwts. of ore are placed in each vat. A quantity of water containing some sulphuric acid, the temperature of the liquid being about 90°C. , is then allowed to run on to the roasted ore. This liquid, after running through the first vat, A, is allowed to permeate through the ore in the second vat, B, and so on throughout the series, so that by the time the acid liquid emerges from the last vat, G, it has become a fairly strong solution of silver sulphate.

The silver in this solution of silver sulphate is then

obtained by replacing it by some cheaper metal, such as copper. The silver thus thrown down is melted up and cast into ingots; whilst the copper which has gone into solution, and is now in the form of copper sulphate, is obtained again by replacing it with some still cheaper metal, such as scrap-iron.

The residues, which (owing to the formation of insoluble compounds with iron oxide, bismuth, &c., and incomplete working) still contain some silver, are fused with more copper ore; and another regulus is so obtained, which again undergoes (after mixture with an entirely new regulus) the process above described.

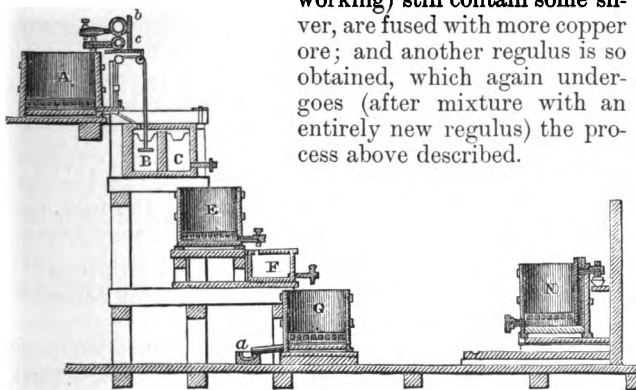


Fig. 38.—Arrangements of Ziervogel's Apparatus. A, Tub with false bottom. b, c, Pipes for admitting acid water into A. B, C, Tank for receiving solution from A. E, F, G, Precipitating tanks. a, Gutter for escape of liquid. N, Tub in which the precipitated silver is treated with sulphuric acid

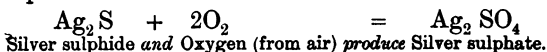
Description of the Furnaces and Apparatus employed in Ziervogel's Process. In the roasting of the regulus it is essential that the heating of the mass should be gradual, and the temperature capable of regulation within certain limits. This is best attained by conducting the operation in a double-bedded reverberatory furnace, which is therefore always employed in this process. The ore is first placed on the upper bed of the furnace; and for the first hour and a half or so the temperature is raised only sufficiently high to convert the iron sulphide into the condition of iron sulphate.

At the end of that time the temperature is raised for

another interval of $1\frac{1}{2}$ –2 hours, during which the copper sulphide is brought into the state of copper sulphate. The mass being still on the top bed, the temperature is a third time raised; when the silver sulphide is converted into silver sulphate.

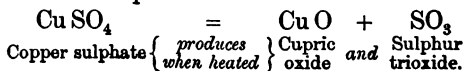
When this has taken place (the whole of the ore having been well stirred during the meantime) the roasting mass is raked on to the lower and hotter bed of the reverberatory furnace; the process of decomposition of the iron and copper sulphates then takes place in consequence of the great elevation of temperature. The upper bed of the furnace is therefore used simply for the preliminary operations in the process of roasting; the completion of the process being brought about on the lower bed.

Chemical Reactions involved in the various operations in Ziervogel's Process. The basis of the Ziervogel Process lies in the fact that the iron, the copper, and the silver sulphides (the primary constituents of regulus) each and all undergo oxidation into the corresponding sulphates when roasted in contact with air, for example thus:—



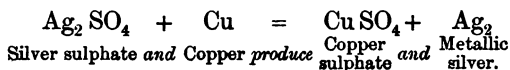
It is in order to ensure the thorough permeation of air throughout the mass that the ore is raked and stirred so many times during the roasting; for unless this be done the upper parts of the ore, and those in direct contact with the air, would alone be "sulphated"; the ore below the surface of the mass would remain almost entirely unacted upon.

The following three sulphates—ferrous sulphate (FeSO_4), cupric sulphate (CuSO_4), and silver sulphate (Ag_2SO_4)—being thus produced, advantage is taken of the fact that ferrous and cupric sulphates are decomposed into their corresponding oxides at a *much lower* temperature than silver sulphate:—

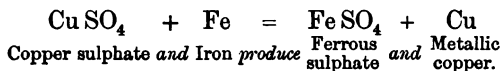


It is, therefore, possible by stopping the heating of the mass at a particular stage to convert the sulphates of iron and copper into oxides, which are insoluble in water; the silver sulphate remaining undecomposed and soluble.

This silver sulphate is obtained in the form of a solution as before described; and the silver is obtained from it in the metallic state by placing metallic copper in the solution. This reaction then ensues:—



Finally, the copper in its turn is obtained from the solution of cupric sulphate by introducing into the solution some scrap-iron:—



Augustin's Process for the Extraction of Silver. Augustin introduced his process at Mansfield in 1849; and this was the only wet method of extracting silver from its ores known before the introduction of Zier-vogel's process.

Augustin's process depends on the following principles:—

(1) The silver in an ore can be converted into silver chloride by roasting with common salt.

(2) The silver chloride thus formed can be dissolved by brine.

(3) The dissolved silver (existing in the state of a chloride) can be precipitated from its solution by metallic copper.

Description of Augustin's process. The silver ores are first made to undergo a preliminary roasting, the object of which is to oxidize or expel all volatile substances, such as arsenic, antimony, and the like. By doing this the consumption of salt is economized, since these volatile metals readily combine with the chlorine

of the salt. Not only do they do this, but the chlorides of these metals (which would certainly be formed) are detrimental to the complete extraction of the silver out of the ores. By first oxidizing them they are not so likely to form chlorides as they otherwise would be.

A charge of the crushed calcined ore together with some 8 or 9 per cent of common salt is then introduced into an ordinary reverberatory furnace, and roasted for a period of about 3 hours, the mass being kept well stirred in the meanwhile. During this time the temperature of the furnace is kept down below the point at which silver chloride melts, since if this melting took place the mass would clot and the complete extraction of the chloride afterwards would require much more time than otherwise.

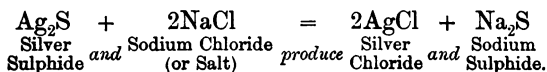
The roasted ore is now "leached" with a hot concentrated solution of ordinary salt. To effect this about half a ton of ore is placed in a number of lixiviation tanks arranged in tiers. These tanks are simply round vats some 14 ft. in diameter and $3\frac{1}{2}$ ft. deep, made of strong oak. They have a similar construction to those used in the Ziervogel process (see fig. 53), being provided with false bottoms made of strong lattice-work, covered with sacking or some other filtering material. Leading out of the space between the false and the true bottom of each tub is a tap, by which any liquid in the tank can be drawn off after having first been filtered.

A hot solution of common salt is then allowed to fall into the topmost tank of the series, and, after percolating through the ore contained in this tank, is drawn off by means of the tap at the bottom. During its passage it has combined with a large part of the silver chloride in the ore. This liquid is then made to run on to the ore in the next tank in the series. Here it combines with more silver chloride, so that by the time the salt solution is run off from the last tank of the series it has become (by the successive additions of silver chloride) a tolerably concentrated solution of that substance.

To extract the silver out of this solution, the liquor is

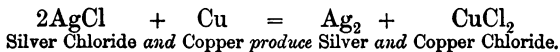
pumped into the first of a series of "precipitating vats". These coincide in every particular with the lixiviation tanks just described, except that on the false bottom of the vat is placed a perforated copper plate. On the silver chloride solution coming into contact with the copper plate, the silver is given up or exchanged for copper. This silver is then deposited as a fine gray powder, while the copper plate gradually wastes away.

Chemical Principles involved in Augustin's Process. Let us suppose that the ore treated is one containing the silver in the form of silver sulphide; then on roasting this with salt in the manner described, silver chloride is produced. The reaction that ensues may be represented by the following chemical equation:—

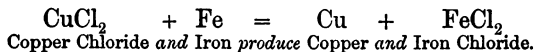


When the silver chloride thus produced is dissolved by the salt solution or brine (which is the next operation performed) a double chloride of silver and sodium is formed. This is a soluble salt.

From this solution the silver is extracted by means of copper placed at the bottom of the "precipitating vats". This is simply an interchange of silver for copper, thus:—



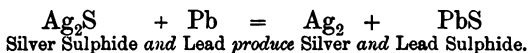
Finally, the copper is obtained from its state of solution as copper chloride by means of scrap-iron. The reaction is the same in principle as that above, viz.:—



This copper—which is termed "cement copper"—may be, and often is, utilized for precipitating the silver instead of the copper plates.

Extraction of Silver from Ore by means of Lead. This method of extracting silver is now

largely carried on in England, and also at the large metallurgical works at Freiberg in Saxony. The silver ores to be treated, which come mostly from South America, are by this method smelted in conjunction either with metallic lead, with galena, or with rich lead slags (these two latter materials being capable of yielding metallic lead during the smelting of the ore). The molten lead then exercises a reducing action on the silver compound contained in the silver ore; the lead being exchanged for the silver. Thus if the silver is present as silver sulphide, the following reaction would ensue:—



As soon as the silver assumes the metallic state, it immediately passes into and combines with the excess of lead present, and an alloy of silver and lead is thus obtained.

The extraction of the silver from this argentiferous lead is then carried out either by Pattinson's or by Parkes's process. Sometimes, however (as at Freiberg), both processes are used together in this way. The concentration of the silver in the argentiferous lead is carried down to a certain point by means of the Pattinson process, after which Parkes's process is brought into use, and the final concentration of the silver accomplished by its aid. By this means the cost of desilverizing the lead is considerably lessened, as the cost of working the Pattinson process (especially in its final stages) is somewhat great.

The alloy of silver, lead, and zinc obtained by the aid of Parkes's process is then first distilled (when the zinc is expelled, its vapour being condensed and the same metal used over and over again), and the resulting rich alloy of lead and silver cupelled. By this means the lead is converted into litharge and so got rid of, only pure silver remaining on the "test" of the cupellation furnace, which silver is thereafter run off and cast into ingots.

SECTION IV.

METALS OTHER THAN THE FOREGOING.

CHAPTER XVII.

COPPER AS A METAL: COMPOUNDS OF COPPER WITH OXYGEN AND WITH SULPHUR—THE ORES OF COPPER.

Copper and its Symbol. This metal was known to the ancients; the Romans first obtained it from the Island of Cyprus, and called it *Æs Cyprium* (Cyprian bronze), this term being afterwards contracted to *Cuprum*. The symbol or sign used by chemists to denote the elementary body *copper* consists of the first two letters (*Cu*) of its Latin name (*Cuprum*).

Physical Properties of Copper. Copper possesses a brownish-red colour when freshly fractured, and a metallic lustre. When broken it gives a finely granular fracture; it has a specific gravity of 8.8. The ruddy colour of copper distinguishes it from every other substance except cyano-nitride of titanium, a compound found on certain blast-furnace slags. Copper crystallizes in the cubic system, and crystals may be obtained either by fusion of the metal or by precipitation from a salt of copper. Its melting point is 1050°C. , and it volatilizes in the oxyhydrogen blow-pipe flame. At temperatures near to its melting point copper becomes very brittle, and can then be pounded in a mortar. When copper passes from the liquid to the solid state it expands. The properties of malleability and ductility are highly developed in copper; but, if hammered cold, it becomes hard and brittle, and its malleability is only restored after annealing at a red heat.

Copper is an excellent conductor of electricity; calling

the electrical conductivity of silver 100, then that of pure electrotype copper is 96·4. The presence of other elements markedly decreases its conductivity; thus with the presence of $\frac{1}{10}$ th per cent of arsenic the conductivity of copper falls to 67·7. Copper containing even a small quantity of phosphorus is unsuited for electrical purposes, its conductivity being again considerably lessened.

Action of Acids upon Copper. Hydrochloric acid attacks copper very slowly; strong sulphuric acid dissolves it when heat is applied, sulphur dioxide being evolved. Nitric acid at once attacks copper, converting it into copper nitrate.

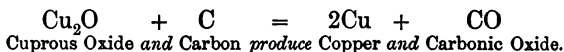
Cuprous Oxide (Cu_2O). Copper combines with oxygen in two proportions, forming the sub-oxide and the monoxide of copper.

Copper sub-oxide or cuprous oxide (Cu_2O) contains 88·8 per cent of copper and 11·2 per cent of oxygen. It is crimson-red in colour with a metallic lustre, crystallizes in the cubic system, and occurs native in Cornwall and other districts.

When a piece of copper foil is heated in the Bunsen flame, both the oxides of copper are formed, thus:—



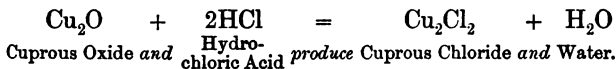
On heating cuprous oxide with carbon reduction takes place, with the formation of metallic copper and carbonic oxide, thus:—



Cuprous oxide combines with silica, forming an easily fusible silicate. The presence of cuprous oxide in copper renders that metal brittle, or, as it is technically termed, “dry”, or “underpoled”.

Cuprous oxide is deposited as a red precipitate when a solution of grape-sugar is heated with a mixture of copper tartrate and caustic soda. (This is “Fehling’s test” for the detection of grape-sugar.)

Cuprous oxide is readily dissolved by the mineral acids, with the production of the cuprous salts of copper; *e.g.*:—

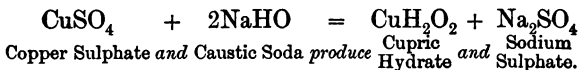


Monoxide of Copper, or Cupric Oxide. The monoxide of copper or cupric oxide is blackish-brown in colour, each molecule consisting of one atom of copper and one atom of oxygen—its formula, therefore, being CuO . Cupric oxide contains 79·85 per cent of metallic copper, together with 20·15 per cent of oxygen. It crystallizes in the rhombic system.

Monoxide of copper, like the suboxide, is easily reduced to the metallic state when heated with carbon.

This monoxide is formed as blackish scales upon the surface of the metal when copper is heated to redness in contact with either air or oxygen.

On adding a solution of caustic soda or caustic potash to a solution of a copper salt (copper sulphate, for example), a pale-blue precipitate consisting of cupric hydrate is thrown down:—



When the solution containing cupric hydrate is boiled, the latter substance is decomposed; water being given off, while copper monoxide remains:—



Cuprous Sulphide. Each molecule of cuprous sulphide (Cu_2S) consists of two atoms of copper combined with one atom of sulphur.

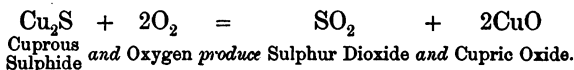
This substance exhibits a strong tendency to combine with other metallic sulphides to form complex compounds.

Cuprous Sulphide heated with access of air. Cuprous sulphide remains unchanged when heated to a

high temperature out of contact with air. But if heated in contact with air, sulphur dioxide gas is evolved, and cupric oxide is formed. The reaction takes place in two stages, and is dependent upon the temperature at which the operation is conducted. First, the cuprous sulphide is converted into copper sulphate (CuSO_4), cuprous oxide (Cu_2O), and cupric oxide (CuO).

Secondly, if the temperature is now raised the copper sulphate is decomposed; evolving sulphur dioxide and oxygen. This oxygen at once combines with the cuprous oxide, converting it into cupric oxide.

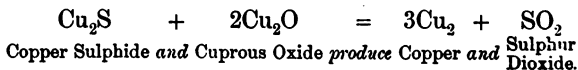
Thus although intermediate products are formed, the *ultimate* compounds produced are sulphur dioxide and cupric oxide, thus:—



Cuprous Sulphide heated in admixture with Cuprous Oxide. If cuprous sulphide be intimately mixed with an oxide of copper, so that the proportion of sulphur in the copper sulphide to the oxygen in the copper oxide is such as to form sulphur dioxide when the mixture is heated to the melting point of copper, then the whole of the copper contained in the mixture will be reduced to the metallic state.

In practice, the smelter roasts the copper sulphide till it has been sufficiently oxidized into cuprous oxide to form sulphur dioxide with the remaining unaltered sulphide; he then heats the mixture up to the melting point of copper, and thus obtains metallic copper.

The following equation illustrates the reaction between the sulphide and the suboxide of copper:—



Cuprous Sulphide heated in admixture with Monoxide of Copper. If cuprous sulphide be mixed with the monoxide of copper and the mixture strongly

heated, a reaction similar to that in the preceding case takes place.

Metallic copper and sulphur dioxide are formed, as represented in the following equation:—



Copper Sulphide and Monoxide of Copper produce Copper and Sulphur Dioxide.

Cuprous Sulphide heated in admixture with Sulphate of Copper. The nature of the products formed by heating sulphide of copper with sulphate of copper will depend upon the temperature to which the mixture is subjected, and also upon the proportions which the two compounds bear to one another. In all cases sulphur dioxide is formed, and in addition either metallic copper, cuprous oxide, or cupric oxide. Thus:—



Copper Sulphide and Copper Sulphate produce Copper and Sulphur Dioxide.

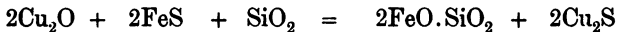


Copper Sulphide and Copper Sulphate produce Cuprous Oxide and Sulphur Dioxide.



Copper Sulphide and Copper Sulphate produce Cupric Oxide and Sulphur Dioxide.

Cuprous Oxide heated with Sulphide of Iron and Silica. The following equation illustrates the reaction which takes place when cuprous oxide (Cu_2O), sulphide of iron (FeS), and silica (SiO_2) are heated together:—



Cuprous Oxide and Iron Sulphide and Silica produce Ferrous Silicate and Copper Sulphide.

The ferrous silicate forms a black vitreous opaque slag; the copper sulphide is simply a regulus, formed by the sulphur of the iron sulphide replacing the oxygen of the copper oxide.

Cuprous Sulphide heated with Carbon. At a

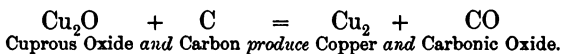
high temperature carbon decomposes sulphide of copper with the production of metallic copper.

Cuprous Sulphide heated with Iron. On heating the sulphide of copper (Cu_2S) with iron, only a partial reduction of the sulphide ensues, a certain percentage of metallic copper being obtained.

Copper heated with Suboxide of Copper (= cuprous oxide). Copper possesses the power of dissolving or taking up copper suboxide; and when the maximum quantity of copper suboxide has been taken up, the metal is termed "dry copper". Such copper is brittle both when hot and when cold; its fracture is granular and uneven; and when melted and cast into an ingot mould, the ingot has a shallow longitudinal furrow on its upper surface. "Dry copper" contains up to 9 or 10 per cent of cuprous oxide; and as a consequence of this there is a great diminution in its tenacity.

The presence of a small quantity of this dissolved cuprous oxide appears to be necessary, however, to ensure the required malleability of commercial copper; the proper proportion of cuprous oxide is about 1 to 1.5 per cent; and the copper is then known as "tough pitch", an ingot then presenting a level surface. When all the suboxide of copper is removed, an ingot of copper shows a ridge instead of a furrow upon its upper surface; and this ridge is no doubt due to the escape of oxygen or sulphur dioxide gas while the metal was in the molten state.

Copper and Carbon. *Copper and carbon* do not combine chemically while they are in the simple or elementary state. Carbon, in the form of charcoal or anthracite, is heated with copper in the refining processes; with the result that any copper suboxide which is present is decomposed, and its oxygen removed:—



Overpoled Copper. This term is applied to copper from which *all* the copper suboxide has been removed.

Overpoled copper is brittle at a red heat; or is "red short".

Ores of Copper. These may be classified as follows:—

1. Native copper.
2. Ores containing copper oxides.
3. Ores containing copper carbonates.
4. Ores containing copper sulphides.
5. Ores containing copper silicates.

The value of any ore of copper depends partly upon the amount and nature of the impurities associated with it, and also upon the manner in which the copper is combined with other elements. The presence of blende and of barytes is very detrimental; these substances forming pasty infusible slags, through which the molten metal cannot easily sink.

Character and Chemical Composition of the Ores of Copper.

1. **Native Copper.** This mineral crystallizes in the cubic system; but usually forms irregular masses or interspersed grains. Its specific gravity is 8·9. Native copper is often extremely pure, any impurities which it may chance to contain being chiefly iron and silver. Enormous masses of native copper occur in the Lake Superior district; one mass alone yielding 800 tons of pure copper. Native copper is also found in Cornwall, Wales, &c.

2. **Ores containing Copper Oxides.** (a) *Cuprite* or cuprous oxide, Cu_2O . This ore contains 88·8 per cent of copper and 11·2 per cent of oxygen. It crystallizes in the cubic system; and is deep crimson in colour with a metallic lustre. It is mined at the Burra-Burra mines, South Australia; and in the Lake Superior district.

(b) *Melaconite*, or *Tenorite*, is the black oxide of copper, CuO . This oxide, chemically termed cupric oxide, contains 79·85 per cent of copper, and 20·15 per cent of oxygen. It usually occurs associated with cuprite.

3. **Ores containing Copper Carbonates.** (a) *Malachite*, or green copper carbonate ($\text{CuCO}_3 \cdot \text{CuH}_2\text{O}_2$), contains

57·45 per cent of copper. The largest masses of this ore occur in the Urals. At Alderley Edge, in Cheshire, it forms the cementing material of a sandstone.

(b) *Azurite*, or blue copper carbonate ($2\text{CuCO}_3 \cdot \text{CuH}_2\text{O}_2$), contains 55·26 per cent of copper. It occurs associated with malachite.

4. **Ores containing Copper Sulphides.** (a) *Copper pyrites* (CuFeS_2) is a double sulphide of copper and iron, containing 34·5 per cent of copper, 30·54 per cent of iron, and 34·89 per cent of sulphur. It possesses a brass or golden-yellow colour; and is much softer than iron pyrites (which it much resembles), being easily scratched with a knife. This is the most abundant and the most important ore of copper. Cornwall and Chili are the chief localities for this ore.

(b) *Redruthite*, or copper glance (Cu_2S), contains 79·7 per cent of copper. It is a common Cornish mineral.

(c) *Erubescite*, or purple copper ore (Cu_3FeS_3), yields, when pure, 55·58 per cent of copper. It is a valuable ore of copper, and is found in Tuscany, Cornwall, and Canada.

(d) *Fahlerz*, or *Tetrahedrite*. This is a highly complex ore of copper containing also antimony, arsenic, silver, &c.

The following table shows the composition of an ordinary Fahlerz or gray copper ore:—

				Per cent.		Per cent.
Copper, ...	...	...	...	30	to	38
Antimony, ...	...	...	...	16	„	25
Arsenic, ...	...	...	...	2	„	11
Silver, ...	...	...	...	0·5	„	10
Iron, ...	...	...	...	0	„	8
Zinc, ...	...	...	...	2	„	7
Sulphur, ...	...	...	...	25	„	26

5. **Ores containing Copper Silicates.** *Chrysocolla*:— This is a hydrated silicate of copper, found chiefly in Chili. Its chemical formula is $\text{CuSiO}_3 \cdot 2\text{H}_2\text{O}$.

Many other ores of copper occur in nature, as *atacamite*, a hydrated oxy-chloride of copper; copper uranite; and copper sulphate; and when these occur in sufficient

quantities they are mined, smelted, and the metal so extracted.

CHAPTER XVIII.

PROCESSES BY WHICH METALLIC COPPER IS EXTRACTED FROM ITS ORES.

Copper Smelting. Copper is extracted from its ores in five ways:—

1. By the reverberatory method.
2. Blast-furnace method.
3. A combination of the reverberatory and blast-furnace methods.
4. Wet methods.
5. Electro-chemical methods.

Where fuel is plentiful, either the reverberatory, the mixed reverberatory, or the blast-furnace processes are employed; the wet methods being used when the price of fuel is high, and also for extracting copper from copper residues.

Wet methods are also preferable where the ores are poor in copper, and where they contain a profitable percentage of silver.

In the reverberatory methods, sulphur is the chief reducing agent; carbon and carbonic oxide, with sulphur, being the reducing agents when copper ores are smelted in blast-furnaces. By whatever process the extraction of copper from its ores is effected, they each and all depend on the great affinity which copper has for sulphur, thus enabling it to form a *regulus*.

The Welsh Process of Copper Smelting. At Swansea different varieties of copper ores from all parts of the world are smelted; some containing not more than from 3 to 15 per cent of copper; while others contain from 15 to 25 per cent of that metal. The rich ores are usually mixed with the poor ores; and in addition rich oxides and carbonates of copper are introduced at certain stages of the process.

The Welsh process consists essentially of a series of alternate roastings and fusions; the following diagrammatical scheme shows the various operations employed:—

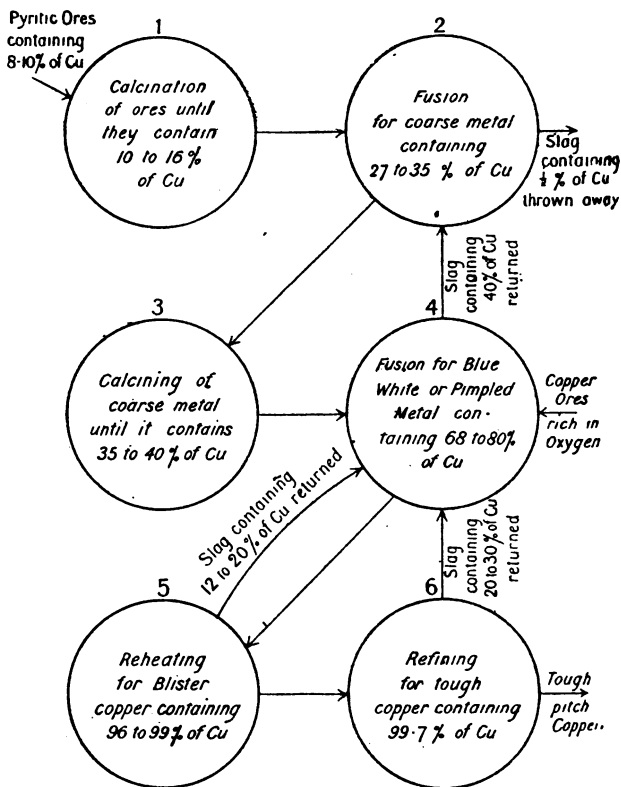


Fig. 54.

The general outline of this Welsh process is as follows (see also the printed "scheme", fig. 54):—

1. **Calcination.** The ores of copper are mixed to

gether and imperfectly calcined (see fig. 55), a large proportion of the sulphur and arsenic present being thus expelled; but care is taken that sufficient sulphur is left to form copper sulphide (Cu_2S) with the whole of

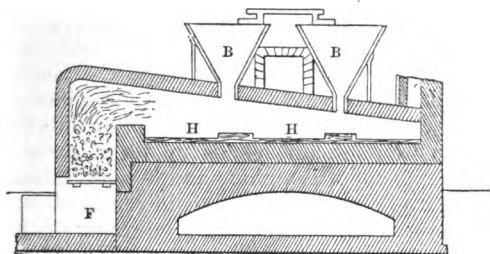


Fig. 55.—Reverberatory Furnace for Calcining Copper Ores. H, H, Hearth. F, Fireplace. B, B, Hoppers.

the copper present; and also to form iron sulphide (FeS) with an amount of iron chemically equivalent to the copper. The remainder of the iron is oxidized, forming ferric oxide, Fe_2O_3 .

2. **Fusion.** The imperfectly calcined ore is next mixed

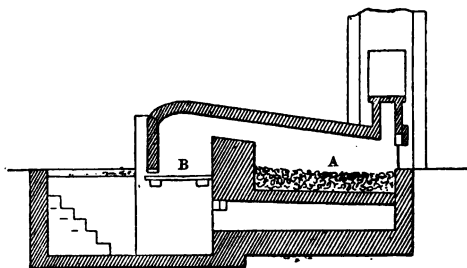


Fig. 56.—Reverberatory Furnace for Melting Calcined Copper Ores. A, Hearth covered with sand. B, Fire-grate.

with fresh copper ore, and with metal slag from operation No. 4 (see below). The whole is then melted together (fig. 56). The copper having a great affinity for sulphur, and the iron a great affinity for oxygen, chemical reac-

tions ensue. The ferric oxide in the calcined ore is reduced to ferrous oxide, FeO ; and passes away as silicate of iron in the slag. The oxide of copper is changed into sulphide of copper, which, together with some sulphide of iron, forms a regulus. The final result is a regulus termed "coarse metal", containing from 27 to 35 per cent of copper.

3. **Calcination of the "Coarse Metal".** The regulus is coarsely broken up, and again partially calcined. Some of the sulphur is here driven off as sulphur dioxide; but most of the iron sulphide yields up its sulphur to the copper, forming copper sulphide and becoming itself converted into iron oxide, which is again removed as a slag. Some of the iron sulphide remains, however, unchanged.

4. **Fusion for the Second Regulus or "White Metal".** The calcined material is melted with copper ores free from sulphur and rich in oxygen, the object being to remove the remaining sulphur from the iron sulphide (thus producing iron oxide which is removed in the slag) and to form a regulus as free as possible from iron sulphide. The regulus thus formed contains from 68 to 80 per cent of copper, and is termed "Pimpled", "White", or "Blue metal", according to the amount of iron sulphide still contained in it.

5. **Roasting.** The pigs of regulus from the last operation are roasted, and the result is known as "Blister copper". The copper sulphide is here oxidized by the air, and the cuprous oxide (Cu_2O) which is produced reacts on the copper sulphide (Cu_2S) which remains, producing sulphur dioxide gas and metallic copper.

6. **Refining.** By this process (see p. 182) tough or refined copper is finally obtained, containing from 99.7 to 99.8 per cent of copper.

Furnaces employed in the Welsh Process. The furnaces in which both the calcining and the fusing of the copper ore are conducted are ordinary reverberatory furnaces, termed the "calcining" and the "melting" furnace respectively.

Calcining Furnace. This is a firebrick-lined rever-

beratory furnace having a flat bed (see fig. 55), and usually built with four holes in the roof for the introduction of ore by means of hoppers, B. Since the temperature required for the calcining of the ore is not very great, the laboratory, H, is comparatively large as compared with the area of the fireplace, F. On account of the large amount of noxious gases, such as sulphur dioxide and arsenious oxide, which are expelled from the ore, the stack of the furnace is usually built very high. The charge is worked and rabbled by means of long iron rakes from the working doors of the furnace, of which there are usually either two or four on each side. On the completion of the process the charge is raked out through a hole in the bed of the furnace adjacent to each working door, and then drops down into one or more arched chambers placed directly under the bed of the furnace. These chambers are also in connection with the stack, since the roasted ore continues to evolve sulphur dioxide during its cooling.

Melting Furnace. This furnace (also known as an "ore furnace", see fig. 56) differs from a calciner in the fact that the bed, A, is constructed of consolidated sand, and is made sloping; and also in the fact that a much larger grate, B, is used. The calcined ore is introduced on to the bed of the furnace by means of hoppers in the roof. This bed is oval in shape, and inclines toward a tap-hole; there being, therefore, no arched chambers in the construction of this "melting" furnace. The sand of the bed is of an average thickness of about 1 ft. to 1½ ft. There is only one working door to the furnace, and that is placed at the stack end.

In both calcining and melting furnaces the fuel used is coal, usually a mixture of free-burning and caking coals.

THE CHEMISTRY OF THE WELSH COPPER PROCESS.

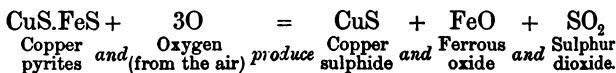
The Reactions which occur in the Welsh Process. In the Welsh copper-smelting process the main object aimed at is the formation of a regulus or copper

sulphide; and also the removal of the iron sulphide first by oxidizing it, and secondly by causing the iron oxide so produced to combine with silica to form ferrous silicate (a slag). Lastly, we have the production of metallic copper from the regulus by the mutual reactions of the copper sulphide and the copper oxide.

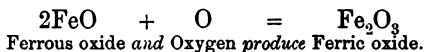
The following equations may be taken as representing the reactions which take place during the smelting of copper ores in the Welsh process. The numbers refer to those over the circles in the scheme previously given on p. 172.

(1) **First Roasting or Calcination Process:—**

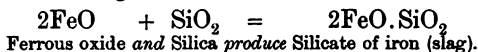
(a)



(b)



(2) **First Melting Process:—**The excess of iron is first removed as a slag:—

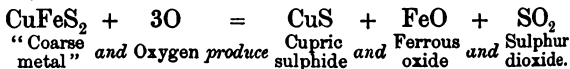


In this first melting process, also, the copper sulphide and the iron sulphide combine, thus:—

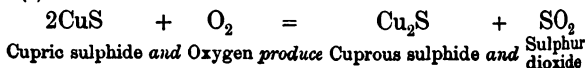


(3) **Second Roasting or Calcination Process:—**

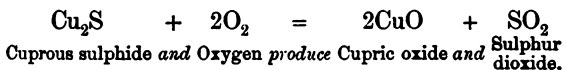
(a)



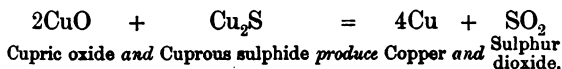
(b)



(c) A portion of the cuprous sulphide thus formed is oxidized to cupric oxide:—



(4) **Second Melting Process:**—



PRACTICAL DETAILS OF THE WELSH COPPER PROCESS.

1. **Calcination in the Welsh Process.** The calcination, or more properly the *roasting*, is effected in a reverberatory furnace having a deep fireplace (fig. 55); a thick mass of bituminous coal mixed with anthracite fills the fireplace, and in order that incomplete combustion only may occur, air is admitted through the ash-pit. The ore is introduced on to the bed of the furnace through hoppers in the roof; the roof is arched, and the bed of the furnace is separated from the fireplace by a fire-bridge. Three and a half tons of ore are roasted at a time; the temperature of the furnace is gradually raised, and the ore is stirred through the open side doors. When the roasting is sufficiently advanced, the side doors are closed and the temperature raised still higher to decompose any sulphates which have been formed. The oxidation of the ores is only partial; but may be made complete by finely dividing the material. The roasting is completed in from twelve to twenty-four hours.

2. **Melting of the Calcined Copper Ores.** A very high temperature is necessary to melt the calcined ores; to produce the required heat the reverberatory furnace (fig. 56) must therefore have a large fireplace compared with the laboratory part. The bed of the furnace is composed of tightly packed sand and metal slag, and is about 25 inches thick; the bed is a hollow-shaped cavity which slopes down in all directions towards the tap-hole.

Under the furnace is a hollow arch, so that should the products break through the furnace they may be collected. About 22 cwts. of calcined ore and metal slag are charged into the furnace, and the working door is then closed. The slag is the first to melt; and after about five hours the copper-iron regulus also melts, forming a fluid mass. If the ores are very impure, fluor-spar or some similar flux is added.

The slag is withdrawn by means of a rabble, and the regulus is then run out through the tap-hole into water, in order to granulate it. This melting of the calcined ore does not eliminate the injurious metals, such as arsenic and antimony. It has for its object the collection of all the copper into the regulus, and the transference of the useless substances as much as possible into the slag.

External Characters of the Products of the Melting Process. The regulus obtained by melting the calcined ore is termed "coarse metal". This is a bronze-coloured porous mass, the slag formed along with it (termed "ore furnace slag") being black in colour and very brittle.

Composition of Coarse Metal and of Ore-furnace Slag. "Coarse Metal" contains from 27 to 35 per cent of copper, and consists of the sulphides of copper and of iron (CuS and FeS), together with a little nickel and cobalt.

The following is an analysis of "coarse metal":—

Copper,	...	...	...	...	...	27·2 per cent.
Iron,	...	...	...	...	...	39·4 "
Nickel, }	...	...	...	...	...	·6 "
Cobalt, }	...	...	...	...	...	·6 "
Sulphur,	...	...	...	...	...	32·8 "

"Ore-furnace Slag" consists principally of ferrous silicate, $\text{FeO} \cdot \text{SiO}_2$, and is for the most part thrown away. It rarely contains more than ·5 per cent of copper.

The following is an analysis of this slag:—

Silica,	30 per cent to 52 per cent.
Ferrous oxide,	17 " " 36 "
Alumina,	1.4 " " 8.7 "
Lime,	2 " " 16 "
Magnesia,	0.6 " " 5.4 "
Cuprous oxide,	0.4 " " 0.7 "

3. Calcination of the Granulated Coarse Metal.

This second calcination is effected in a second reverberatory furnace similar to that used in the first calcination. From 8 to 10 tons of coarse metal are roasted at a time; the temperature being kept low at first, but raised considerably towards the end of the operation. The charge is rabbled from time to time to prevent it from clotting; there is no true fusion, the process taking from 20 to 36 hours. The main object of the process is to convert the iron sulphide present in the "coarse metal" into iron oxide. Sulphur dioxide is also produced, together with oxide of copper; but the main object of the process is to convert the iron sulphide present in the coarse metal into oxide of iron. All the sulphur must not be driven off, or the next operation (No. 4) will be rendered impossible.

4. Melting of Calcined Granulated Coarse Metal. This operation is conducted in very much the same way as in the fusion for "coarse metal". Slags rich in silica are added to the calcined coarse metal to flux away as much as possible of the iron oxide produced in the previous roasting process.

One ton of calcined regulus is mixed with 12 cwts. of fresh copper ores rich in oxygen, and the whole is heated rapidly to complete fusion. The slag which is formed is termed "metal" slag, and contains about 4 per cent of copper. It is run into moulds, and added to ores in other stages of the process. The regulus consists chiefly of cuprous sulphide, and is termed "white", "blue", "pimpled", or "fine" metal. The character of this regulus, however, depends upon the relation between the amounts of the sulphide and the oxide of copper present in the regulus at this stage.

White Metal. This substance contains about 76 per cent of copper, and is produced when the amount of oxidized ores (or ores rich in oxygen) added to the calcined coarse metal is sufficient to convert the whole of the iron sulphide present into oxide. This regulus is compact and brittle, breaking with a crystalline or granular fracture.

ANALYSIS OF WHITE METAL.

Copper,	77.5 per cent.
Iron,	2.2 "
Sulphur,	20.1 "

Blue Metal. This is a regulus which passes insensibly into white metal. It is formed when the total amount of oxidized ores is not in sufficient quantity to oxidize the whole of the iron sulphide, some of the latter compound then remaining undecomposed, and passing into the regulus.

The following analysis of "blue metal" may be compared with the analysis just given for "white metal":—

ANALYSIS OF BLUE METAL.

Copper,	56.7 per cent.
Iron,	16.3 "
Nickel,	1.6 "
Silver,	1.2 "
Sulphur,	23.0 "

Blue metal is very brittle, having an uneven fracture and a purplish-blue colour.

"Pimpled Metal" is produced when the oxidized ores are in *excess*, causing a partial reduction of the regulus to copper, together with the formation of cuprous oxide.

Metal Slag. This material (which is the slag formed along with the "white", "blue", or "pimple" metal) breaks with an uneven or conchoidal fracture, giving sharp edges; hence it is sometimes termed "sharp" slag. It possesses a dark gray colour, and is frequently crystalline in structure.

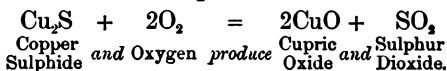
ANALYSIS OF METAL SLAG.

Silica, ...	...	24.9	per cent to 36	per cent.
Ferrous oxide, ...	...	54	" "	57 "
Alumina, ...	...	0.8	" "	3.8 "
Lime, ...	...	1.2	" "	2.8 "
Magnesia, ...	...	0.2	" "	0.4 "
Cuprous oxide, ...	...	0.7	" "	9 "

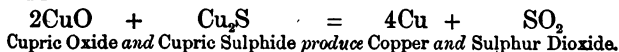
Metal slag usually contains from 4 to 5 per cent of copper disseminated as shots of metal, and is smelted together with calcined ores in operation No. 2.

Moss Copper. This substance is nearly always produced in "blue metal". It is an extremely pure kind of copper, forming wire-like strings upon the surface of the regulus. It has a mossy appearance, and is often found filling the vesicles or air-spaces in the blue metal.

5. Roasting of Copper Regulus. The roasting of the white, blue, or pimpled metal is conducted in a reverberatory furnace with a very deep hearth. Air is admitted through the fireplace, or through slits on either side of the furnace. At this stage of the operation the sulphur is eliminated from the regulus. Part of the sulphur is removed as sulphur dioxide:—



The cupric oxide (CuO) which is also formed acts upon the remaining copper sulphide, reducing it to metallic copper and sulphur dioxide, thus:—



Any iron which may be present is scorified, and passes away in the slag. The pigs of white metal are placed at the top of the hearth, so that the regulus, as it melts, runs down towards the bottom of the hearth, leaving the impurities behind. The pasty mass of regulus in the bottom of the hearth is now reduced to metallic copper by the reaction of the cupric oxide on the cuprous sulphide as mentioned above. The product is termed

"Blister copper", and the slag, which is rich in copper, is called "Roaster slag".

Blister Copper contains from 96 to 99 per cent of copper, the impurities which it contains being chiefly sulphur, iron, tin, and antimony. The surface of the ingot is covered with blisters due to the escape of sulphur dioxide gas as the molten metal solidifies.

Roaster Slag is of a reddish-brown colour, and is usually dense and compact in structure. It contains from 12 to 20 per cent of copper, partly as dissolved cuprous oxide, and partly as metallic shots. This rich slag is returned to operation No. 4 to be smelted with the "coarse metal".

Copper Bottoms. In the fusion of the calcined "coarse" metal for "white" metal, an alloy of copper with tin, antimony, arsenic, lead, and other impurities is formed on the bottom of the furnace. This alloy is detached, and if it contains but little tin it is sent into commerce as "hard metal". Should there be any gold and silver present in the copper ores these metals are concentrated in the copper bottoms and afterwards extracted. (See Ziervogel's method, p. 155.)

6. Refining of Blister Copper. The "blister copper" still contains many impurities, and these must be removed before commercial copper is obtained. The grate of the reverberatory furnace in which the refining is conducted is of larger area than those of any of the furnaces already considered. Six to eight tons of blister copper in the form of pigs are loosely packed in the furnace, and the temperature is rapidly raised to the point at which copper melts. Sufficient air is admitted to oxidize the whole surface of the molten copper, which soon becomes covered with a scoriaceous slag containing a large proportion of cuprous oxide. Any sulphur and arsenic which may be present are at the same time oxidized, and driven off as vapours. The temperature is now raised for 3 or 4 hours in order to fuse the blister copper, and the slag is then drawn off. The fusion in the presence of air is continued till a sufficient quantity

of cuprous oxide has been formed to completely saturate the copper; and this is shown by the layer of copper oxide which covers the surface of the molten mass. It is now ready for poling.

Poling. The surface of the molten copper is now covered with a layer of powdered anthracite. A pole of birch wood, or of green oak, is put into the molten copper, when the wood rapidly decomposes (owing to the high temperature), with as a result the evolution of certain gases. These gases in escaping cause the liquid copper to splash about, thus exposing fresh portions of the metal to the reducing action of the layer of anthracite. The gaseous hydrocarbons given off from the wood also act upon the cuprous oxide in the lower part of the molten mass, and reduce it to metallic copper. If the poling has not been carried far enough the copper is "dry", and a test-piece cracks at the edges when hammered, owing to its brittleness. It is then said to be "underpoled".

When the right degree of poling has been effected, the copper is termed "tough pitch"; it is then malleable and soft. If it has been "overpoled" the copper loses its ductility and malleability, and must be oxidized again.

Refined copper contains from 99·7 to 99·8 per cent of metal. The refinery slag contains large quantities of dissolved cuprous oxide, and is usually melted up again for the production of white metal.

CHAPTER XIX.

ZINC OR SPELTER: ITS COMPOUNDS WITH OXYGEN AND WITH SULPHUR—EXTRACTION OF METALLIC ZINC FROM ITS ORES—BRASS.

Zinc as a Metal. Our knowledge of the metal zinc does not appear to extend farther back than about the middle of the 16th century, although the ores of this metal must have been employed by the ancients in the manufacture of their bronze.

In the form in which zinc is put on the market it is known to brassfounders and others as "spelter". The ingots of zinc or spelter are in the form of rectangular slabs, and on fracture exhibit on their broken faces a remarkably high lustre. The zinc is then seen to also possess a very crystalline structure, the crystals intersecting with one another so as to give the metal a foliated appearance. Every possible gradation, however, from coarsely crystalline to granular spelter, can be obtained by regulating the rate of cooling of the metal and the temperature to which the zinc is heated before it is poured out into the ingot moulds.

Physical Properties of Zinc. At the ordinary temperature of the air ($= 15^{\circ} \text{C.}$) zinc breaks easily. It is only when the temperature of the metal is raised to about 150°C. that it can be rolled into sheets or drawn out into wire; but when further heated to 200°C. it becomes exceedingly brittle, and can be readily crushed to powder. Zinc can be made malleable after rolling by annealing at a low temperature. Its fracture is granular or crystalline, varying with the treatment it has received. The specific gravity of zinc which has cooled slowly from a state of fusion is 7.178; if cooled quickly its specific gravity is 7.145. Both hammering and rolling increase the density of zinc.

The most common impurities met with in commercial zinc are iron, lead, arsenic, and antimony; and these affect the quality of the metal very considerably. Thus the presence of only $\frac{1}{2}$ per cent of lead renders zinc so brittle that it cannot be rolled.

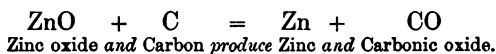
The melting point of zinc is 415°C. , and it boils at a temperature of a little over 1000°C. Its electrical conductivity is 28.1, taking silver as 100.

Action of Oxygen and of Acids upon Zinc. When exposed to moist air zinc becomes covered with a layer of oxide, which then preserves the metal beneath from further oxidation. Commercial zinc is readily attacked by dilute hydrochloric and sulphuric acids; *pure* zinc is, however, only slowly acted upon by these acids.

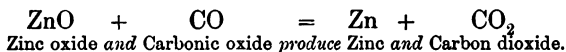
In contact with air or oxygen zinc oxidizes easily at a red heat, forming the oxide of zinc, ZnO .

Reduction of Oxide of Zinc by Carbon. Oxide of zinc (ZnO) can only be completely reduced to metallic zinc by carbon when the latter is in sufficient quantity to decompose *all* the carbon dioxide which is formed, so that only carbonic oxide is produced.

The following equation illustrates the action of carbon on zinc oxide:—

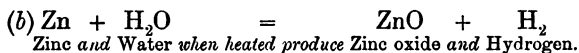
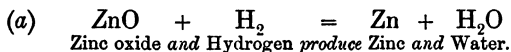


Reduction of Oxide of Zinc by Carbonic Oxide. Carbonic oxide is a powerful reducing agent, and readily reduces zinc oxide, thus:—



But in actual working the reduction of the zinc oxide is not complete because carbon dioxide is present; this latter compound (being an oxidizing agent) partly re-oxidizes the metallic zinc, and thus to some extent neutralizes the action of the carbonic oxide.

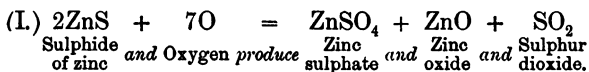
Reduction of Oxide of Zinc by Hydrogen. Hydrogen gas reduces zinc oxide to the metallic state, water being formed at the same time. But the water is decomposed at a red heat by the reduced zinc, and hydrogen and zinc oxide are then again produced. Thus:—



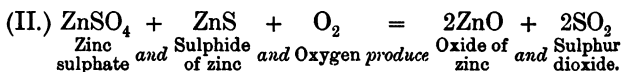
The second equation (b) shows that if the water vapour (H_2O) be allowed to remain in contact with the reduced zinc, part of the zinc will be oxidized and will be thus converted into zinc oxide once more. But by passing a *brisk* stream of hydrogen gas over the heated zinc oxide, the water vapour produced (as in equation a) by

the reduction of the oxide is conveyed away almost as fast as it is formed, and in consequence very complete reduction of the metallic oxide takes place.

Sulphide of Zinc heated with access of Air. Zinc combines with sulphur, forming zinc sulphide, ZnS . On heating finely divided sulphide of zinc in contact with air, sulphur dioxide is given off and both the oxide and the sulphate of zinc are formed. It is very difficult to effect the complete decomposition of the sulphide of zinc.



And then, when the temperature is raised, the sulphide and the sulphate react upon one another as follows:—



Ores of Zinc. Zinc does not occur in nature in the uncombined state.

The principal ores of zinc are the sulphide, the carbonate, and the silicate. Many other minerals containing zinc are known, but the extraction of that metal from the associated gangue is attended with too many difficulties to render them of much commercial value.

Physical Characters and Chemical Composition of the Ores of Zinc.

(1) The mineral commonly known as **Blende** or “Black Jack” is sulphide of zinc, ZnS . It occurs both massive and crystalline, the massive form being the most useful ore. It possesses a brown to black colour, due to the iron which it contains, and has a resinous lustre. Blende occurs in beds and veins associated with pyrites and galena, from which it is separated by mechanical dressing. When pure, blende contains 67 per cent of zinc and 33 per cent of sulphur, some varieties, however, con-

taining as much as 5 per cent of cadmium. It occurs in Cornwall, Wales, and Alston Moor, and is indeed very widely distributed.

(2) **Calamine**, or zinc carbonate, ZnCO_3 , contains 52 per cent of zinc. It is usually yellow or brown in colour, with a vitreous lustre, and forms rounded masses. Calamine is one of the best ores of zinc, requiring less fuel for its reduction than blende. It occurs in Derbyshire, Sardinia, and near Santander in Spain.

(3) **Willemite**, or Silicate of zinc, Zn_2SiO_4 , contains 58.1 per cent of zinc, and is often found associated with another silicate of zinc termed electric calamine, $\text{Zn}_2\text{SiO}_4 + \text{H}_2\text{O}$, which yields 53.7 per cent of zinc. These ores are valuable when in sufficient quantity, and are found in New Jersey, U.S.A., and at Altenberg.

(4) **Zincite**, or zinc oxide, ZnO , contains 80.25 per cent of zinc and 19.75 per cent of oxygen. It occurs intimately associated with *Franklinite* and *Willemite* at Franklin, New Jersey.

Methods of Extracting Zinc. Zinc is extracted from its ores by simple distillation processes; and all improvements of recent years in the direction of zinc smelting have simply been in the methods of firing, the shape of the muffles, &c.

Blende is the ore of zinc most commonly employed; and this is first roasted at a strong heat in a reverberatory furnace to convert it into zinc oxide; which is then reduced to metallic zinc by means of carbon and carbonic oxide. The methods used for smelting the calcined sulphide and other ores of zinc are:—

1. English process.
2. Silesian process.
3. Belgian process.
4. A mixed Belgian and Silesian process.

I. English Process for the Production of Zinc. This is a rather costly method of extracting zinc from its ores; 25 per cent less zinc being obtained than by the other processes named above.

The furnace is octagonal in plan, and about forty feet high; a fireplace, A, runs down the centre of the furnace, on either side of which is a series of Stourbridge fire-clay crucibles, B, each crucible being 4 feet high and 2 feet

6 inches wide at the top (see fig. 57).

The base of each crucible is perforated, each hole or perforation having attached to it a short cast-iron tube, c. Calcined blende is mixed with finely-divided coke or coal-dust and is charged into the crucibles, and a lid is luted on to each crucible. The temperature is now raised, and before long brown fumes emerge from the cast-iron pipes; these are due to the cadmium contained in the zinc. When these brown fumes cease to be evolved, a sheet-iron tube, D, is attached to the end of each of the

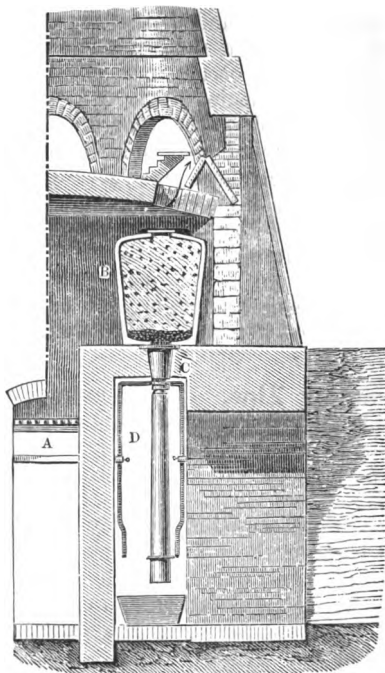


Fig. 57.—English Zinc Furnace. A, Fire-grate. B, Crucible. c, Short cast-iron tube. D, Sheet-iron tube.

cast-iron pipes, and the zinc fumes are thereby conveyed to a cool iron receiver where they are condensed. At intervals, an iron rod is pushed up the sheet-iron tube to prevent it from being stopped up by the condensed zinc. From 22 to 27 tons of ore are required to produce 1 ton of zinc.

Roasting or Calcination of the Blende. Up to a few years ago, it was the custom to calcine the crushed and washed blende in flat single-bedded reverberatory furnaces of the ordinary type. Now, however, these calciners are made with one bed over the other, so that the roasting takes place in double-bedded reverberatory furnaces. These furnaces are built about 10 feet long and 6 feet broad; and, instead of coal being used as fuel, the waste heat from the reduction furnaces is utilized. The method of roasting is then as follows:—On to the top bed of the furnace a charge of from 5 to 8 cwts. of blende is placed, and raked evenly over the hearth. This is roasted for 12 hours, and is then raked through a hole in the top bed on to the bottom bed of the furnace; its place being taken by a fresh charge of blende. While lying upon the lower bed the zinc ore is exposed for another 12 hours to a stronger heat, the mass being stirred at intervals. It is then raked out from the bottom bed of the furnace and transferred to the smelting furnaces; its place being now taken by the ore on the upper bed. The ore may thus be said to undergo two roastings before it is completely calcined. The calcined zinc ore is then mixed with some form of carbon and distilled in some form of furnace as described above.

II. Silesian Process for Zinc. The chief difference between the Silesian and the Belgian processes is in the shape of the retorts. In the Belgian method the retorts are supported only at their two ends (see fig. 60); but in the Silesian process they are supported throughout their entire length (see fig. 59).

The loss of zinc in this process is about 9 per cent of the quantity contained in the ore; being greater than in the Belgian process. The Silesian process is very suitable for smelting poor ores; especially ores containing lead, which yield fusible slags.

From 53 to 65 lbs. of calcined ore, 23 lbs. of powdered coal, 6 lbs. of zinc residues, and 9 lbs. of coke, are mixed together and charged into the retorts; heat is supplied to the furnace by burning coke (or more usually gaseous

fuel), a regenerative furnace being attached to utilize the heat of the waste gases. Any cadmium which may be present in the zinc ores is first evolved as brown fumes (the so-called "brown blaze" of the smelter), and may be condensed and collected. The zinc subsequently distils over, the vapour passing into cool condensers, upon whose sides it settles down in stalactitic metallic masses. This deposit is afterwards remelted in a separate furnace.

Retorts and appendages employed. The retorts employed in the Silesian process are \cap -shaped in

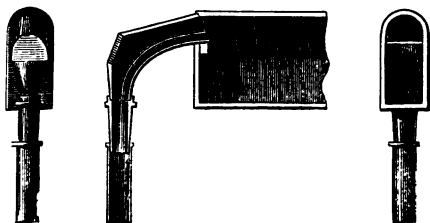


Fig. 58.—Retorts for Silesian Zinc Furnace. B, retort. A, Movable part of nozzle. B, Cast-iron tube. C, Sheet-iron tube.

section; being 3 to 4 feet long, 1 foot 6 inches high, and 8 inches wide. They are composed of a mixture of equal parts of fire-clay and old retorts ground to a powder; in England, Stourbridge clay is largely used for the manufacture of these retorts.

At one end of the retort near the top is an opening, attached to which is a fire-clay pipe or nozzle, making an angle of 45 degrees downwards with the retort (see fig. 58). The side of the nozzle, A, away from the retort is movable; so that the smelter is able to watch the progress of the distillation. Attached to the end of the fire-clay nozzle is a vertical cast-iron tube, B; to which is again attached a tube of sheet-iron, C, in which most of the zinc condenses.

Description of the Silesian Furnace. A Silesian furnace differs materially in form from a Belgian furnace, for in the former the muffles or retorts used are supported throughout their entire length in the furnace, and

not only at the ends as in the Belgian furnace. The Silesian furnace partakes of the nature of a reverberatory furnace, having an arched roof (see fig. 59). Into the sides of the furnace are fitted some 30 or 40 Silesian retorts, A. These rest side by side on the horizontal bed, B, of the furnace. Sometimes, however, instead of being arranged in a single row down each side of the reverberatory furnace they are arranged in a double row, one above the other; but this plan is not often adopted in this country.

Melting of Distilled Zinc. The distilled zinc is removed from the condensers and melted in a small furnace; if it contains much lead it is then poured into moulds deeper at one end than the other.

The alloy of lead and zinc, when cooled *slowly*, separates completely, the lead being found in the deeper part of the mould, with the zinc above it.

In large works the crude zinc is melted in reverberatory furnaces in masses of 20 or 30 tons at a time; and is frequently kept in the molten state for 2 or 3 days to ensure the complete separation of the lead. Any sulphur and iron which may be present, then combine to form iron sulphide; which separates out from the molten zinc on solidifying.

III. Belgian Process for the Extraction of Zinc. This process is suitable for zinc ores which contain pyrites. It is the process commonly employed in this country for the extraction of zinc from its ores. The calcined blende is mixed with anthracite and shovelled

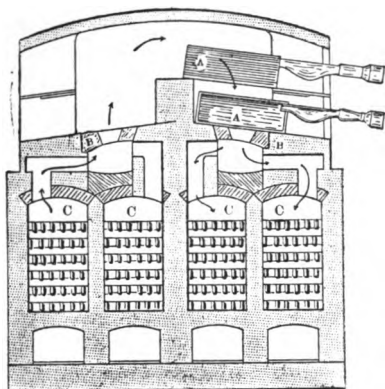


Fig. 59.—Silesian Zinc Furnace. A, Silesian crucibles. B, Bed of furnace. C, Regenerator.

into cylindrical retorts, to one end of which condensing receivers are attached to collect the zinc fume.

The retorts are arranged in tiers, each furnace containing about sixty retorts.

These retorts are placed in an inclined position in the

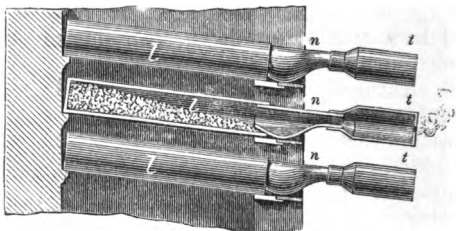


Fig. 60.—Retorts for Belgian Zinc Furnace. *l*, Cylindrical retorts. *n*, Fire-clay nozzles. *t*, Sheet-iron tubes.

furnace, the back of each retort being higher than the front.

The calcined ore is first stamped to a powder, and is then again roasted in double-bedded reverberatory furnaces, whereby the amount of sulphur present in the ore is brought down to about 1 per cent. It is then mixed with from one-third to one-half of its weight of powdered anthracite, and about 25 lbs. of the mixture are placed in each retort. The heated carbon combines with the oxygen of the zinc oxide, producing carbonic oxide which burns at the mouth of the fire-clay nozzles with a pale-blue flame. This flame afterwards changes to green, owing to the actual burning of some of the zinc; when this is observed, the sheet-iron tubes are attached in order to condense the issuing zinc vapours.

Retorts and Appendages used in the Belgian Process. The cylindrical retorts, *l*, are 3 feet 6 inches long, and 8 inches in diameter (see fig. 60); they are composed of fire-clay, mixed with powdered coke, ground-up retorts, and sand, in the following proportions:—

Fresh fire-clay	...	...	...	...	30 parts.
Baked fire-clay,	...	...	...	...	27 "
Coke,	...	...	...	...	18 "
Old retorts,	...	...	...	...	15 "
Sand,	...	...	...	...	10 "

Care must be taken that the clay does not contain pyrites, or this will burn out and render the retorts porous. The retorts are dried for two months, but are not annealed before using them.

To the open end of each retort (fig. 60) is attached a fire-clay nozzle, *n*, 12 inches long, in which most of the zinc condenses; and to the end of this nozzle is fixed a sheet-iron tube, *t*, for condensing the "fume", which consists of a mixture of zinc oxide and powdery zinc.

Each retort lasts for from 15 to 20 days; and for every 78 tons of ingot zinc, 4 or 5 tons of powdery zinc oxide are obtained.

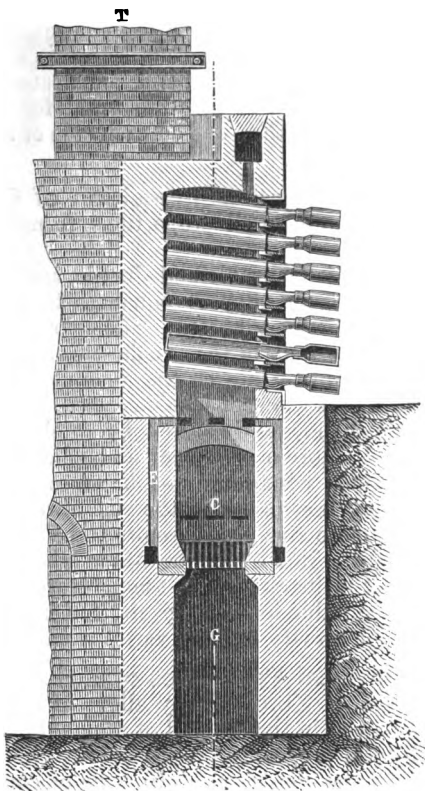


Fig. 61.—Belgian Furnace. *G*, Ash-pit. *C*, Fireplace grate. *Z*, Flues for hot air. *T*, Chimney.

Description of the Belgian furnace. The furnace in which the cylindrical fire-clay retorts used in the Belgian system of smelting zinc ores are placed, has the form of an arched recess, above which are the flues com-

municating with the chimney; and below is the fireplace, c (see fig. 61). Such a recess is usually made to hold about 50 retorts; these being supported by the masonry of the furnace at their extremities only. The middle portion, therefore, of each retort is exposed directly to the action of the fire and the heated gases therefrom. In practice, it is usual to build four of these Belgian furnaces together, one on each side of a rectangular mass of brickwork.

Nature and Composition of Brass. Zinc and copper unite in all proportions, forming the alloy called brass.

Brass is malleable and ductile, and possesses a fibrous structure, an alloy of equal parts of zinc and copper being extremely fibrous. The colour of brass varies with the proportions of the two metals of which it is composed, approaching white as the amount of zinc is increased, and red as the copper is increased.

Brass may be deposited by an electric current from a mixed solution of copper and zinc. When exposed to continued vibration, brass becomes very brittle. On remelting brass some of the zinc always volatilizes and is lost; more zinc has therefore to be added to compensate for this. Brass soon tarnishes when exposed to moist air; it melts at a lower temperature than copper, and is very suitable for castings and for engraving upon. The specific gravity of brass varies from 7.5 to 10.

Physical Properties of various Alloys of Copper and Zinc. Many alloys of copper and zinc are employed in the arts, all of which differ slightly in their physical properties.

A brass consisting of 10 parts of copper and 1 part of zinc has a reddish-yellow colour, but when these metals are in the proportion of 2 parts of copper to 1 part of zinc the resulting alloy is full yellow in colour.

An extremely malleable alloy is made by melting together 60 parts of copper and 40 parts of zinc.

Pinchbeck consists of 75 parts of copper and 25 parts

of zinc, and is not altered in density by working, or by either slow or rapid cooling after heating.

Sterro-metal is exceedingly tough and has enormous tenacity, having a great power of resistance. It contains—

Copper,	...	...	...	...	55	to	60	per cent.
Zinc,	...	...	...	...	39	"	40	"
Iron,	...	...	...	...	1·7	"	3	"
Tin,	...	...	...	...	0·8	"	2	"

Muntz's Metal. This alloy is much used for the sheathing of ships. Its composition is as follows:—Copper, 60 parts; zinc, 40 parts; and lead, 2 parts. The lead does not appear to be an essential constituent.

In the production of Muntz's metal the copper is melted on the bed of a reverberatory furnace, the zinc being melted in a separate pot at one end of the furnace. When both are ready, the zinc is ladled into a receptacle in front of the furnace and the copper is run into it. The alloy is finally poured into iron moulds lined with clay.

CHAPTER XX.

LEAD AS A METAL: ITS COMPOUNDS WITH SULPHUR AND WITH OXYGEN.

Lead as a Metal. The history of this very familiar metal dates back at least to the occupation of this country by the Romans (B.C. 55 to A.D. 110); for old lead workings are found in several parts of Britain from which lead was extracted by them during their sojourn here. To this Latin race or people lead was known by the name of "*Plumbum*", and its symbol Pb is derived from this Latin word.

Lead has very wide uses in commerce, the most important being for making pipes, and the solid rods from which bullets are made. It is not usual now to *cast* these pipes and rods, as was previously done, but rather

to make them by means of what is known as "squirting". In this operation the lead is first melted and then allowed to very nearly solidify. When in this pasty condition the metal is forced through a hole by hydraulic pressure, the diameter of the hole being equal to that of the piping or rod required.

Physical Properties of Lead. Perfectly pure lead is destitute of crystalline structure when cast in moulds, but when allowed to flow away from a partially solidified mass of the metal the latter crystallizes in octahedra. Lead melts at a temperature of 325°C . When fractured at a temperature near to its melting point it presents a columnar structure. Its specific gravity is 11.37, and its density is slightly increased by rolling. Its electrical conductivity is low, being 7.7 at 17°C ., silver being taken as 100. When freshly cut, lead has a bluish-gray colour and silvery metallic lustre. Lead is so soft that it can be readily cut with a knife and deeply scratched even with the finger-nail. It is malleable and ductile, and possesses but little tenacity, this last property depending partly upon the temperature to which the metal is subjected and partly on the duration of the stress or extending force. Its resistance to fracture by twisting or torsion is $\frac{1}{10}$ th that of wrought-iron. Two pieces of clean lead can be welded together even when cold.

Lead decomposes boiling water, and is insoluble in commercial sulphuric acid; it is readily dissolved, however, by nitric acid. The presence of a small quantity of arsenic increases the hardness of lead.

Action of Heat upon Lead. Lead melts at from 326° to 334°C . according to its purity, and vaporizes or volatilizes into the air, the volatilization being aided by oxidation.

On roasting lead in air, the metal combines with oxygen, forming lead oxide or litharge, PbO , which floats upon the surface of the molten lead, forming a scum which increases in thickness as the roasting is continued.

Heat considerably lessens the tenacity of lead.

Autogenous Soldering. When two sheets of lead are joined together by melting the metal forming their overlapping edges (thus causing them to form one continuous sheet), they are said to be "autogenously" soldered together.

The sheets of lead forming the casing of sulphuric acid chambers, for example, are always autogenously soldered, since if ordinary solder were used it would soon be corroded by the acid. In this case the edge of one sheet of lead is laid about 2 inches over the edge of another sheet, and the oxyhydrogen flame is run along the overlap. The two edges of metal then fuse together, forming a joint thicker and consequently stronger than the remainder of the leaden sheet.

Action of Air upon Lead. When freshly cut lead is exposed to the air it rapidly tarnishes, becoming covered with a layer or film of oxide of lead. This film of lead oxide acts as a protective coating, preventing any further action of the air upon the lead. Only *moist* air is able to thus convert lead into lead oxide, pure dry air having no action upon a bright surface of the metal.

Action of Water upon Lead. *Pure* water has no action upon lead. But water containing dissolved air attacks lead; the oxygen of the air combining with the lead and forming lead oxide, which is at once dissolved by the water, lead hydroxide being then produced. The presence of chlorides and of ammonium salts in the water assists in this dissolving of the lead oxide. The presence of sulphates or carbonates in the water, however, retards the corrosive action, as they soon form an insoluble coating of lead sulphate or lead carbonate on the surface of the metal, which coating then protects the metal from further action.

The use of lead pipes (which is almost universal) for conveying potable waters depends on the fact that these waters almost invariably contain calcium carbonate and calcium sulphate (lime salts). These two substances rapidly combine with the clean interior surface of the lead piping, and produce an insoluble coating of lead

sulphate and lead carbonate, which then protects the lead from any further action of the water.

Protoxide of Lead. The protoxide of lead (PbO) is obtained by roasting lead in air. When first formed after the fusion of the lead it is termed *massicot*, the term litharge being reserved for the same compound formed when the heat is raised so as to cause the massicot itself to melt.

Molten litharge when cooled slowly becomes red in colour; but when cooled quickly it assumes a yellow colour. It crystallizes in thin hexagonal scales, and volatilizes below a white heat. When heated to 300°C . in air, litharge combines with more oxygen, and is converted into the red oxide, Pb_3O_4 , thus:—



Litharge is easily reduced to metallic lead by such reducing agents as carbon, carbonic oxide, hydrogen, and cyanogen (CN). Even at a temperature of 100°C . the protoxide of lead (litharge) is reduced by carbonic oxide. This protoxide or monoxide of lead is only slightly soluble in water; it is, however, readily acted upon by acids and by caustic alkalies.

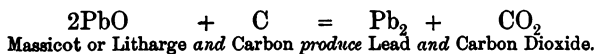
MODE OF FORMATION OF PROTOXIDE OF LEAD BY DRY METHODS.

Massicot. The variety of lead protoxide known as “massicot” is prepared by exposing molten lead to the oxidizing action of the air at a moderate temperature. The lead is then said to be “drossed”, and the furnace in which the operation is conducted is called a “drossing furnace” or “oven”. Such an oven is simply a reverberatory furnace about 11 feet long and some 9 feet broad, having a hearth sloping from back to front and also to some extent from each side toward the centre. The oven is provided with three doors, the larger and central one serving for the introduction of the charge and rabble, the other two doors being for the fuel (coal).

A ton and a half of pig-lead is laid on the bed of the oven, and the temperature is then raised to the required point. The lead, as it melts, runs down the sloping hearth and collects in a pool near the front of the furnace, owing to its passage being there blocked by a dam. The temperature is now increased till the molten metal assumes a dull red heat, when a rabble is introduced and the mass is well stirred. Oxidation then rapidly ensues, and the lead oxide or massicot is pushed up the slope of the hearth as fast as it forms. A period of about 24 hours is generally sufficient to oxidize all the lead. The massicot is then raked out of the oven and allowed to cool. It is now ground to powder in water, and conducted by the aid of running water into tanks, where it settles and is collected. The concluding operation is to dry the massicot, which is done in a reverberatory furnace at a low temperature.

Litharge. For the production of this form of the protoxide of lead a high temperature is required, as it is only formed by melting the lead oxide itself. A full red heat is sufficient to do this, and on this account litharge is usually made in a cupellation furnace. The litharge then formed is treated in the same manner as massicot; the molten oxide being first run off and allowed to cool, then powdered, and carried by a stream of water into settling tanks, out of which it is collected and dried in the same way as before.

Action of Carbon upon Protoxide of Lead. Carbon acts as an ordinary reducing agent when heated to a moderately low temperature along with either massicot or litharge. That is to say, the carbon abstracts the oxygen from the lead oxide (so leaving the lead in the metallic state), and combines with it to form carbon dioxide, thus:—



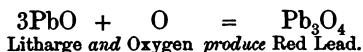
Fusibility of Metallic Oxides. Many metallic oxides are very infusible, requiring a high temperature

before passing into the liquid state. If, however, these oxides are fused with protoxide of lead, their melting points are lowered and they are readily fusible. Different metallic oxides require different amounts of lead oxide to effect this fusion. Thus:—

1 part of		requires	1.5 parts of PbO
1	" Cuprous oxide	"	1.8
1	" Cupric oxide	"	8
1	" Zinc oxide	"	4
1	" Black oxide of iron (Fe_3O_4)	"	10
1	" Ferric oxide (Fe_2O_3)	"	12
1	" Stannic oxide	"	

The oxide of arsenic (As_2O_3), when added to fused protoxide of lead, produces so fluid a compound that when dropped upon a stone slab it breaks up into minute globules, which roll away in the same manner that mercury does when allowed to fall.

Red Lead. "Red lead", or *minium* (Pb_3O_4), is another of the oxides of lead. It is red in colour, and is obtained by the action of air on litharge at a red heat, or about 300°C ., thus:—



At a higher temperature the red lead is decomposed, losing oxygen, and is then reconverted into litharge.

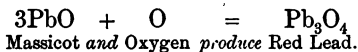
This red oxide of lead is also produced when lead is heated to a dull red heat along with alkaline lead nitrate.

The preparation of red lead is effected in a small reverberatory furnace, having a fireplace on each side; the bed of this furnace is slightly concave.

The lead to be used must be free from impurities, especially copper; about one ton of this lead is placed in the furnace and exposed to an oxidizing atmosphere. The lead melts and combines with oxygen, producing *massicot*, PbO ; this latter substance forms a scum upon the surface of the molten metal, and is scraped off as fast as it forms. A fresh surface of lead is thus always exposed to the air, and the oxidation being continued the whole of the metal is converted into *massicot* in about 24 hours.

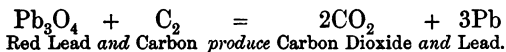
When cold the massicot is moistened with water and ground to a powder. Finally it is washed and conveyed by a stream of water into settling tanks.

The massicot has now to be converted into red lead. For this purpose the dried massicot is spread upon the bed of a reverberatory furnace, and is heated to a temperature of 300°C . for two days. The atmosphere of the furnace is an oxidizing one, and the lead monoxide rapidly combines with oxygen, forming the higher oxide (Pb_3O_4):—



The massicot is frequently stirred, and is at last all converted into a red powder. The furnace is then closed and the red lead allowed to cool slowly. When cool the red lead is ground up, washed with water, and passed between rollers; it is then ready for use.

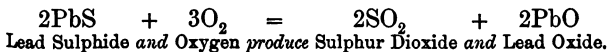
The principal impurities in commercial red lead are brick-dust and red ferric oxide, which are added as adulterants. Red lead is easily reduced when heated with carbon, thus:—



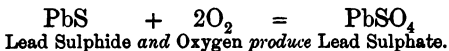
Owing to the readiness with which red lead gives up its oxygen, it acts as a strong oxidizing agent.

When red lead is dissolved in nitric acid, a brown-coloured powder remains behind. This consists of the dioxide of lead or "puce powder" (PbO_2).

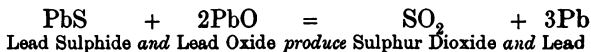
Action of Heat and Air upon Sulphide of Lead. On heating sulphide of lead in contact with air, a portion of it is converted into lead oxide and another portion into lead sulphate. This is shown in the following equations, thus:—



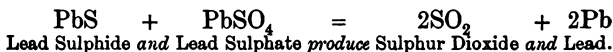
And



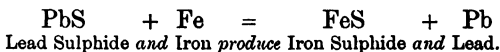
A mixture of lead sulphide, lead oxide, and lead sulphate is thus formed. If the heating be continued these three substances react upon one another, with as a result the production of metallic lead and sulphur dioxide gas. Thus:—



And



Action of Iron when heated with Sulphide of Lead. When iron is heated with sulphide of lead, reduction of the sulphide takes place, and metallic lead is formed together with sulphide of iron:—



Action of Metallic Lead on Sulphide of Silver. Silver and lead have a great affinity for each other, and for this reason many of the processes employed for the extraction of silver from silver ores depend upon the readiness with which silver combines or alloys with lead. When metallic lead is heated with sulphide of silver the whole of the silver passes into and alloys with the lead.

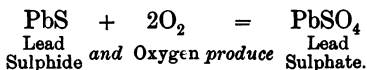
Combination of Sulphide of Lead with other Sulphides. Sulphide of lead forms definite chemical compounds with other sulphides, some of which are of commercial importance. Many of these complex sulphides occur in the natural state; thus a very productive silver ore termed *Freislebenite* consists of silver sulphide, lead sulphide, and antimony sulphide; and its chemical composition may be represented by the formula



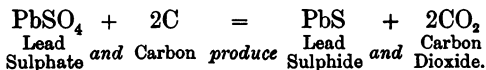
Compounds consisting of sulphide of lead combined with the sulphides of arsenic, copper, and bismuth are also well known.

Sulphate of Lead (PbSO_4). This compound contains 68·32 per cent of lead, 10·56 per cent of sulphur, and 21·12 per cent of oxygen. It occurs in the native state forming the mineral termed *anglesite*.

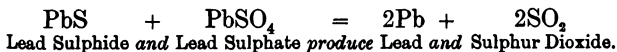
Sulphate of lead may be prepared by adding sulphuric acid to a solution of lead nitrate. It is insoluble in water, but is completely soluble in a solution of caustic potash. When heated with hydrochloric acid it is converted into chloride of lead. If sulphide of lead is roasted at a low temperature in contact with air, it is converted into sulphate of lead: thus:—



Action of Carbon on Sulphate of Lead. On heating sulphate of lead with carbon chemical reactions ensue, which take place in two stages. At a dull red heat part of the sulphate of lead is converted into sulphide of lead: thus:—



If the temperature is now raised the sulphide of lead and the remaining sulphate of lead react upon one another, producing finally metallic lead and sulphur dioxide:—



Action of Iron on Sulphate of Lead. When heated in contact with iron, sulphate of lead is completely reduced to metallic lead, the iron acting the part of a reducing agent. A dark pasty slag is also formed.

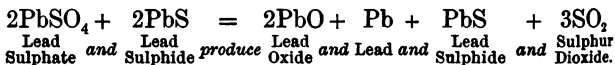
Action of Lead on Sulphate of Lead. The following equation illustrates what takes place when lead and sulphate of lead are heated together:—



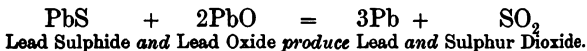
It will be seen that oxide of lead and sulphur dioxide are produced.

Action of Protoxide of Lead on Sulphate of Lead. When heated along with protoxide of lead sulphate of lead becomes very fusible, flowing like water when the temperature is raised to a white heat. The yellow crystalline substance formed by the chemical union of the sulphate and the protoxide of lead is termed a basic sulphate of lead.

Action of Sulphide of Lead on Sulphate of Lead. Sulphide and sulphate of lead react upon one another when heated together. The following two equations represent what takes place:—



Only a very little metallic lead is formed, the lead sulphide being only partly reduced to lead oxide. If the temperature is now raised, the lead oxide and the lead sulphide react upon one another, with the production of more metallic lead and sulphur dioxide: thus:—



CHAPTER XXI.

ALLOYS OF LEAD: ORES OF LEAD: EXTRACTION OF SILVER FROM LEAD

Alloys of Lead. The most important alloys of lead are those containing *tin*. Lead imparts the properties of hardness and tenacity to tin. When the lead-tin alloys are formed there is in some cases a diminution in volume, and in other cases an increase in volume. Lead which contains 4 to 5 per cent of tin smoulders away like wood when heated.

The chief alloys of lead and tin are:—1. **Solder**, con-

sisting either of 66 per cent of lead and 33 per cent of tin; or of 20 per cent of lead and 80 per cent of tin.

2. **Pewter** contains 80 per cent of tin and 20 per cent of lead.

3. **Fusible Metal**; this contains bismuth in addition to lead and tin; bismuth always adding considerably to the fusibility of alloys. An alloy containing 8 parts of bismuth, 5 parts of lead, and 3 parts of tin melts in boiling water (100°C). An alloy containing 5 parts of bismuth, and 1 part each of lead and tin, melts at a temperature of 93°C .

4. **Type Metal** contains antimony, which gives hardness to the alloy. It has the following composition:—Lead 50 per cent, tin 25 per cent, antimony 25 per cent.

Arsenic adds greatly to the fusibility of lead, and this lead-arsenic alloy is used for making shot.

Lead and platinum constitute a readily fusible alloy, equal parts of each metal forming a crystalline mass. For this reason lead salts should never be heated in platinum crucibles.

An alloy used for axle-bearings, and termed "hard lead", contains 62.6 per cent of lead, 20 per cent of zinc, 11.3 per cent of tin, and 6.1 per cent of copper.

Lead and Antimony. These two metals readily alloy with one another; and the presence of a minute quantity of the latter metal renders lead hard and brittle. Lead containing antimony is white in colour, and breaks with a finely fibro-granular, or even granular fracture.

The following experiment illustrates this action of antimony on lead:—Weigh out 1500 grains of pure lead and melt it in a small crucible; add to it 0.8 per cent of antimony, this being effected by wrapping the required quantity of antimony in paper, attaching the paper to a stick, and plunging it into the molten lead. Pour the alloy into a mould. Heat the ingot thus obtained in the furnace to near its melting point, holding it with a pair of tongs. When just about to melt, withdraw the ingot and smartly tap the end of the tongs near the ingot upon a brick; the ingot then breaks, its fractured surface pre-

senting a finely granular-fibrous structure. If too much antimony is added the alloy becomes very hard and white in colour, its fracture being very finely granular.

Perfectly pure lead is difficultly oxidizable; but the presence of only $\frac{1}{8000}$ th part of antimony is sufficient to cause rapid oxidation.

Lead and Arsenic readily combine. Arsenic very greatly increases the fusibility of lead, and also hardens that metal. The presence of small quantities of arsenic also causes lead to rapidly oxidize.

Lead and Zinc do not easily alloy together. When these two metals are melted together, and the molten mixture allowed to cool slowly, a more or less complete separation of the metals takes place. The zinc, having a higher melting point and a less specific gravity than lead, solidifies first and forms a crust upon the surface of the still molten lead.

Lead and Silver. Lead combines with metallic silver, and with silver compounds, to form alloys. Nearly all silver compounds when melted with litharge (PbO) are decomposed, yielding metallic silver which at once alloys with the lead.

Many of the ores of lead, as galena and anglesite, contain some silver; the galena from the Isle of Man yielding from 20 to 60 ozs. of metallic silver to the ton of lead.

The Ores of Lead: their Physical Characters and Chemical Composition. The ores of lead are very numerous, and may be divided into oxides, sulphides, sulphates, and carbonates. Native lead is an extremely rare mineral, and has only been found in the province of Guanaxuato in Mexico.

OXIDES OF LEAD.

Minium, or red oxide of lead, Pb_3O_4 . This is the native red lead, containing 90.66 per cent of lead and 9.34 per cent of oxygen. It is a rare ore, occurring in small quantities at the Snailbeach Mine in Shropshire.

SULPHIDES OF LEAD.

Galena, or lead sulphide, PbS , is by far the most important ore of lead. When pure it contains 86·6 per cent of lead, and 13·4 per cent of sulphur; it usually contains silver, the amount varying from 19 dwts. up to 200 and even 300 ozs. to the ton of ore; and on an average this silver itself contains $\frac{2}{10000}$ th per cent of gold.

Galena is found either massive or crystallized in cubical forms. Its specific gravity is 7·5; and it has a lead-gray colour with a very characteristic metallic lustre.

It occurs in veins and lodes in the carboniferous limestone at Alston Moor, and in Derbyshire; also at the Isle of Man; and at Holywell in North Wales; and in many foreign localities.

Bournonite, or cog-wheel ore, is a sulphide of lead, antimony, and copper, CuPbSbS_3 ; corresponding to lead 42·38 per cent, copper 12·98 per cent, antimony 24·98 per cent, and sulphur 19·66 per cent. It occurs in Cornwall, Freiberg, and Mexico.

SULPHATES OF LEAD.

Anglesite, PbSO_4 , is one of the products formed by the atmospheric oxidation of galena. It contains 68·32 per cent of lead, and sometimes yields as much as 120 ozs. of silver to the ton. *Anglesite* is white or yellowish-brown in colour, with a glassy or resinous lustre. Its specific gravity is 6·2. This ore is found at Leadhills in Scotland; in Pennsylvania, and in Peru.

CARBONATES OF LEAD.

Cerussite, PbCO_3 , when plentiful, is a very desirable ore, containing 77·54 per cent of lead; but it is not very argentiferous. It occurs both massive and crystalline, and is of a dull opaque-white colour, with a specific gravity of 6·5. The chief localities for *cerussite* are Cornwall, and Leadville in Colorado, where it forms a deposit 80 feet thick.

Extraction of Silver from Lead. The desilverization of lead may be effected by three distinct methods:—

1. By *crystallization*, as in the Pattinson process.
2. By the addition of *zinc*, as in Parkes' process.
3. By *oxidation* and subsequent removal of the lead, as in the German and English cupellation methods.

Pattinson's Process for the Extraction of Silver from Argentiferous Lead. This process was devised by Mr. Pattinson in 1833. The process is founded on the *difference in fusibility* between lead and an alloy of lead and silver. On allowing an alloy of silver and lead, in which the lead largely preponderates, to cool slowly, the nearly pure lead crystallizes out first and may be removed, leaving a more fusible molten alloy behind, which is richer in silver than the original alloy. This melting and skimming of the alloy is repeated several times, the amount of silver increasing as more and more of the lead is removed. The concentration of the silver cannot, however, be carried beyond certain limits; an alloy containing $2\frac{1}{2}$ per cent of silver solidifying at the same temperature as that at which lead melts; and for this reason it is not advisable to continue the concentration beyond the point when the alloy contains $1\frac{1}{2}$ per cent of silver.

The crystals of lead which are removed are of course always purer than the molten mass which remains.

Methods of Working in Pattinson's Process. The lead to be desilverized contains perhaps 7 or 8 ozs. of silver to the ton, and is placed in one of the middle pots of the "battery", say into pot No. 4 (fig. 62). When molten it is well stirred, skimmed, and allowed to cool. The pure lead crystallizes out from the rich silver-lead alloy, the crystals being removed by a perforated ladle and transferred to the next pot, No. 5. The remaining rich molten alloy is conveyed to pot No. 3. As the holes in the ladle become clogged with crystals of lead, the ladle is frequently dipped into the small pots which are placed between every two large pots, and which contain molten

lead having a high temperature. The lead crystals are thus melted, and the holes in the ladle thereby cleared.

To the lead that has been transferred to pot No. 5, 126 cwts. of lead containing 4 ozs. of silver to the ton are added; this is melted, skimmed, and allowed to

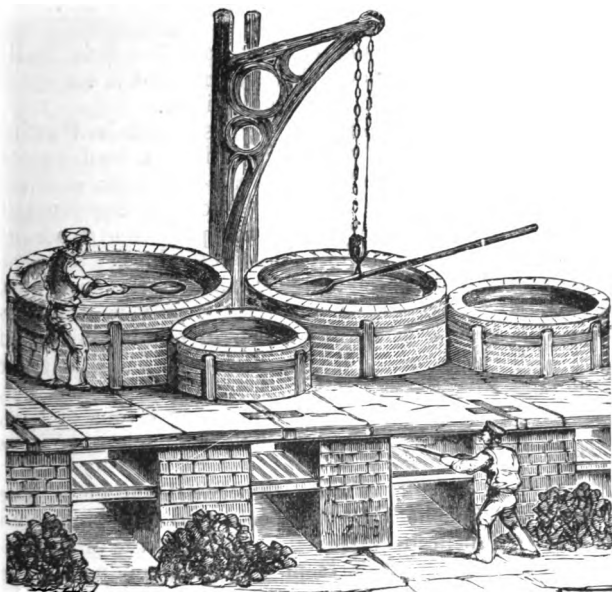


Fig. 62.—Desilverizing Lead by Pattinson's Process. (Only two large pots and two small pots are shown.)

crystallize. The crystallized lead is removed to pot No. 6, and the remaining rich alloy to pot No. 4. This operation is repeated in all the pots, so that lead rich in silver is travelling step by step towards pot No. 1, while lead poor in silver is travelling in a similar manner towards pot No. 8 (see fig. 62).

Argentiferous lead is added to each pot from time to time, so that the same quantity of molten alloy shall be

operated upon in each pot. The scum from the pots Nos. 1 to 4 is afterwards treated by itself; also the scum from the pots Nos. 5 to 8; and that from pots Nos. 9 to 16. Pot No. 1 may contain from 170 to 600 ozs. of silver to the ton; pot No. 8 only 1 oz. of silver to the ton; while pot No. 16 usually contains not more than from 2 to 7 dwts. of silver to the ton.

The rich alloy accumulated in pot No. 1 is finally subjected to cupellation, whereby the lead is converted into litharge, leaving pure metallic silver.

Description of the Apparatus used in Pattinson's Process. The desilverization of lead by the Pattinson process is effected in cast-iron pots, each pot being provided with a separate flue and damper (see fig. 62). Between every two large pots is a small pot containing a small bath of lead having a higher temperature than the silver-lead alloy contained in the large pots. The number and size of the large pots vary considerably, but they are usually sixteen in number, arranged in two batteries of eight pots each. In England these pots hold from $6\frac{1}{2}$ to 7 tons of lead apiece; the last pot, termed the "market pot", holding only 3 tons of lead. In the Hartz district the pots hold as much as 15 tons apiece.

The pots last for about 500 crystallizations. The ladle is a hemispherical bowl, perforated with holes, and is about 18 inches in diameter. Owing to the unhealthiness consequent to the present method of conducting the operation, attempts to employ mechanical labour have been made. Instead of the molten alloy being stirred by hand, steam is forced into the molten metal, which not only agitates the mass but promotes crystallization and the consequent refining of the lead.

Parkes' Process for the Extraction of Silver (by means of Zinc) from the Argentiferous Lead. This process depends upon the fact that silver has a greater affinity for zinc than for lead. Parkes (a well-known Birmingham inventor) introduced this process in 1859.

The argentiferous lead is melted in an iron pot, and skimmed; its temperature is then raised to the melting point of zinc, and from $1\frac{1}{2}$ to 2 per cent of zinc is added, and the alloy vigorously and constantly stirred. The temperature is then gradually lowered, and the zinc, which has a higher melting point than the lead, separates out as a solid crust on the surface of the still molten lead, taking most of the silver and a little of the lead with it. These crusts are removed until the remaining lead shows but a low percentage of silver. They are then heated in cylindrical retorts resembling those employed in the Belgian zinc process (see fig. 60), the retorts being inclined from back to front. The retorts are heated to the melting point of lead, when that metal liquates out, leaving an alloy of zinc and silver behind. The zinc is then removed by distillation and condensed for future use, thus leaving metallic silver alone behind.

English Process of Cupellation. The process of cupellation was known to the Greeks and Hebrews, and was described by Geber in the eighth century.

In the English cupellation process only very rich and pure argentiferous lead is treated, the operation being conducted in two stages. In the first stage the concentration of the silver is continued till the lead contains about 8 per cent of the precious metal. In the second stage the silver is completely separated from the lead, the lead being converted into litharge. All cupellation processes have for their object the oxidation of base metals (which are then removed) by the aid of oxide of lead, and their consequent separation from the precious metals (gold and silver) which are not capable of being thus oxidized.

Construction of Cupellation Furnace. This furnace is of the reverberatory type (see fig. 63). It consists of an oval frame of wrought-iron, which is sometimes fixed, but in England is more usually rendered movable by being supported on a carriage. The longer axis of the oval frame is parallel to the fire-bridge, *F*, of the furnace, and upon the iron frame of the furnace is

constructed the "test" or bed, made of moistened bone-ash mixed with a little pearl-ash. This bed, C, is about 1 inch thick, and is termed the "cupel"; it is very porous, so that it is capable of absorbing the molten oxides of lead

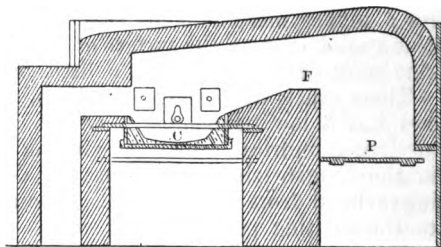


Fig. 63.—English Cupellation Furnace. C, Test or "cupel". F, Fire-bridge. P, Fireplace.

and of the other base metals which are formed during the process.

A series of channels is made through the breast, B, or side of the test in order to remove the molten litharge (see fig. 64). Each furnace is heated by a single fire, a fire-bridge separating the molten metal from the fireplace, P.

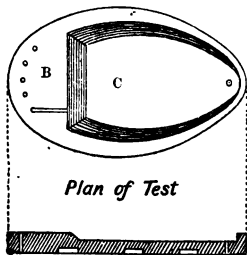


Fig. 61.—C, Test or "cupel". B, Breast of "cupel".

A blast of air is admitted to the furnace through a single twyer at one end of the "test".

Mode of Conducting the Process of Cupellation.

The "test" is heated to redness, and about $5\frac{1}{2}$ cwts. of argentiferous lead are then placed upon the porous bed of the furnace, and melted down. The blast is then turned on, and oxidation of the lead and of any other oxidizable metals which may be present begins. The oxidation continues regularly, and the molten lead oxide or litharge is blown by the blast of air towards the breast of the

"test", where it flows through the channels and drops into a suitable receptacle. More argentiferous lead is added from time to time.

The greater part of the lead is thus removed as litharge, leaving a rich alloy of silver and lead behind which may contain from 500 to 3000 ozs. of silver to the ton.

This rich alloy is tapped out by drilling a hole through the bottom of the "test", and is cast into pigs. The hole is then plugged up with moistened bone-ash, and the whole process recommenced.

The rich alloy so obtained is refined in another furnace, the whole of the lead being thus oxidized into litharge; the unoxidizable silver not being allowed to cool until the whole of the lead has been removed. The silver is then allowed to solidify. After the surface of the silver has become more or less solid it is seen to be thrown up into little protuberances or outgrowths, owing to the escape of occluded oxygen from the silver. This giving off of the oxygen is a sign of the purity of the silver; for if any base metals were present they would combine with the oxygen, and there could be no "spitting" or "vegetating" of the silver.

Finally, the cake of silver is removed from the furnace, cut into suitable pieces, remelted in crucibles, and cast into bars.

Nature of the Products of Cupellation. The silver obtained by the cupellation of argentiferous lead usually contains about 2 per cent of lead, and this is removed by cutting the metal into fragments and melting it slowly on a bone-ash test. The workman judges when the separation of the lead is complete by observing the reflection of the roof of the furnace on the molten bath of silver. Copper and antimony are frequent impurities met with in the silver.

The litharge (PbO) varies in colour and purity with the temperature to which it has been subjected. Most of it contains a little silver, especially that which is absorbed by the "test" towards the end of the operation.

CHAPTER XXII.

EXTRACTION OF LEAD FROM ITS ORES: LITHARGE AND RED LEAD.

Extraction of Lead from the Ore. The operations by which lead is extracted from its ores vary in different countries, and each method has numerous modifications according to the richness and nature of the ores to be treated.

Classification of Processes, and General Chemical Reactions in Lead-smelting. The metallurgical processes for smelting lead ores may be divided into:—

1. Smelting in reverberatory furnaces.
2. Smelting in blast-furnaces.

Only ores rich in sulphide of lead (galena), and with a gangue consisting chiefly of carbonate of lime and but little blende or barytes, can be successfully treated by reverberatory methods. Ores poor in sulphide of lead, or containing much quartz or clay, can be profitably treated in blast-furnaces only. In England two distinct methods are used in reverberatory treatment. They are:—

(a) **Method of Reaction**, in which the ore is converted into sulphide, oxide, and sulphate of lead, the chemical agent producing these changes being atmospheric air; the sulphide, oxide, and sulphate of lead afterwards reacting upon one another, and producing metallic lead.

(b) **Method of Reduction or Precipitation**, in which metallic iron is caused to combine with the sulphur of the lead ore, forming ferrous sulphide, metallic lead being liberated.

METHOD OF REACTION.

Flintshire Furnace for Lead Ores. When the *method of reaction*, or “air-reduction”, is adopted for smelting lead ores, it is usually conducted in a reverberatory furnace, of which the Flintshire furnace (fig. 65) is a type.

Only rich ores containing from 70 to 80 per cent of lead are treated, the metallic lead being produced directly from the ore.

About 1 ton of galena is placed upon the upper part of the hearth of the furnace and roasted for two hours at a temperature below its melting point. The ore must be constantly rabbled to prevent clotting, and a uniform temperature must be maintained. The atmosphere of the furnace is an oxidizing one, which causes part of the sulphur to be removed as sulphur dioxide gas, leaving upon the hearth a mixture of lead sulphide, lead oxide, and lead sulphate.

After two hours the working doors are closed, the temperature is raised, and the charge melted; the sulphide, sulphate, and oxide of lead then react upon one another, producing metallic lead, which runs down to the lower part of the hearth, leaving a mixture of slag and unaltered ore behind.

The slag is now stiffened by throwing lime upon it (the "setting-up" stage), roasted again for another hour, and remelted, when more lead is liberated. The molten lead is now tapped out into a pot heated by a separate furnace, small coal is placed upon its surface, after which it is well stirred, skimmed, and poured into moulds. The slag is either raked out in the pasty condition in lumps, when it is termed "gray slag", or it is run out in a molten state, and is then termed "run slag".

Description of the Flintshire Furnace. The Flintshire furnace is reverberatory, and is usually 11 feet long and 9 feet wide. The hearth is made of moulded clay built upon lead slag, and has a depression on one

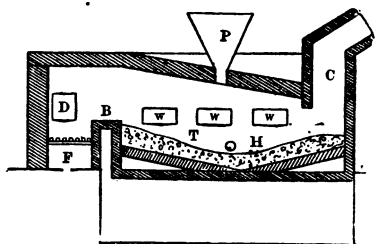


Fig. 65.—Flintshire Furnace. H, Hearth. B, Fire-bridge. F, Fire-grate. D, Fire-door. w, w, Working doors. P, Hopper. T, Tap-hole. C, Chimney.

side connected with a tap-hole. The fire-bridge, B, which separates the laboratory part of the furnace, H, from the fireplace, F, is about 2 feet wide, and the top of it is only about 14 inches from the arched roof of the furnace. There are three doors, W, on each side of the furnace, and the depression made in the hearth is from 18 to 20 inches below the middle door (see fig. 65). Two flues provided with dampers convey the gaseous products to the chimney, C. The whole furnace is constructed of fire-clay bricks (those forming the hearth being lined with gray slag), which need not, however, be very refractory. The ore is charged in through a hopper, P, passing through the roof. A furnace lasts from one to two years.

Nature of the Products of the Flintshire Furnace. The products of the Flintshire furnace are metallic or "pig" lead, and "gray slag".

The pig-lead of course is impure, and has to undergo a refining operation to free it from the iron, copper, and antimony which it contains as impurities.

The gray slag, which on withdrawal from the furnace is in the form of pasty lumps, is a very unhomogeneous gray slag, and may contain (as the following analysis shows) nearly half its weight of lead, usually in the form of oxide, though the metal may be present as sulphate and sulphide as well.

ANALYSIS OF GRAY SLAG.

Lead Oxide, ...	...	...	...	...	...	48.87
Zinc Oxide, ...	...	...	...	...	...	7.52
Lime,...	...	...	...	...	...	22.68
Alumina, ...	...	...	...	...	...	3.13
Ferric Oxide, ...	...	...	...	...	...	3.86
Silica, ...	...	...	...	...	...	13.89
						<hr/> 99.95

The silica in this slag exists in the form of lime silicate; the quicklime added during the smelting having decomposed any lead silicate formed, with, as a result, the production of silicate of lime. Seeing that the slag contains such a large proportion of lead, the slag is re-smelted in the slag hearth so as to extract it.

Cornish Process for Lead Extraction. In the Cornish process lead is extracted from the ore by a method which is really a combination of at least three processes, viz. :—

(1) The “air reduction” or Flintshire process previously described; (2) the reduction by carbon of the oxidized lead produced by calcining the ore; and (3) the reaction which takes place when lead sulphide is heated with metallic iron.

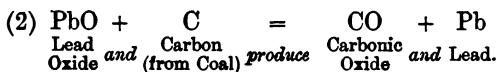
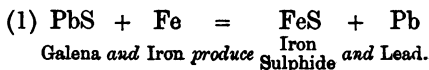
The ores treated in this Cornish process are fairly rich, and consist mostly of galena, in association with which are blende, copper pyrites, &c., and a comparatively large amount of silver.

This lead ore, after being first roughly picked, is made to undergo two operations, viz. :—

(1) Calcination; and (2) a process of melting, in which the metallic lead is separated.

The first operation is conducted in a calciner, the result of which is to convert the ore partly into oxide and partly into sulphate, leaving, however, a portion of the lead in its original state as sulphide.

In this condition the ore is conveyed to the “flowing” or melting furnace, in which operation No. 2 is conducted. Here a large portion of the metal separates out on the mass being melted, owing to the reactions between the lead sulphide, sulphate, and oxide taking place, in the manner described in the Flintshire process. When no more lead separates out, a mixture of lime and anthracite coal, together with scrap-iron, is added to the charge. The remaining lead sulphide and oxide are then decomposed, owing to the following reactions taking place:—



The lead so produced is tapped off, whilst the iron sul-

phide and any impurities contained in the ore form a regulus which is also run off. The gangue of the ore is usually a siliceous one, and accordingly combines with the lime introduced along with the coal to form a slag, which is usually thrown away. If the operations are properly and economically carried out, some 65 parts of lead to every 100 parts of ore can be extracted by this process, the lead carrying about 40 ozs. of silver to the ton.

Description of "Calciner" and of "Flowing Furnace" in the Cornish Process.

(1) **The "Calciner"**. The oxidizing of the ore in the Cornish process is performed in a reverberatory furnace of much the ordinary type, but possessing three doors, one at each side of the furnace and opposite to one another, the third door being in close proximity to the stack of the furnace. The furnace is lined internally with fire-brick, but a hole is left in the roof, through which the charge is introduced. During the working of the furnace this hole is simply closed by a stone slab. A charge of about 2 tons is then laid on the furnace bed and calcined at a high temperature, the ore being rabbled at the end of every hour. About 16 hours after the introduction of the charge the workman rakes the ore into an arched chamber placed below the furnace bed, but communicating with it by a hole in the bed close to each of the side doors of the furnace.

(2) **"Flowing Furnace"**. The partially oxidized ore is now transferred to the "flowing furnace". This is similar in construction to a Flintshire furnace, but possesses five working doors in the same relative position as those in the calciner, the only difference being that there are now four lateral doors instead of two. The bed of the furnace slopes sideways and also from back to front, the tap-hole being placed just behind the fire-bridge. A charge of 2 tons of calcined ore is placed on the furnace-slag forming the bed of the furnace, being introduced through the door at the stack end and then evenly raked over the bed. The temperature is then raised, and kept up for some 3 hours.

During this time the reactions between the lead oxide, the lead sulphide, and the lead sulphate have been taking place, resulting in the separation of metallic lead. This liquid lead is run out into a cast-iron pot placed under the tap-hole. A mixture of lime or fluor-spar and coal, together with about $1\frac{1}{2}$ cwts. of scrap-iron, is now placed in the furnace and mixed by the workmen with the charge. Decomposition of the lead oxide by the carbon of the coal, and of the lead sulphide by the scrap-iron, then ensues, and at the end of about 5 hours this decomposition is usually completed.

The metallic lead thus separated is now tapped out into the iron pot. After this, owing to its lesser specific gravity, comes the regulus, and finally there issues the slag.

Nature of the Products in the Cornish Process. The lead obtained by this process is usually very hard, and requires refining to separate out the antimony which is generally the cause of the hardness. Containing also some 40 ozs. of silver to the ton, the extraction of that metal can be profitably performed.

The "Regulus" consists mostly of iron sulphide formed by the reaction which took place in the furnace between the lead sulphide and the scrap-iron. Besides this, it contains the copper originally present in the ore, together with some mechanically-held lead. It is accordingly melted up again to get out the lead, and then passed on to the copper smelter, who extracts the copper from it.

The slag is composed of silicate of lime, containing only a small amount of lead which it is unprofitable to extract, and this slag is accordingly thrown away.

Ore Hearth for Lead Extraction. This form of furnace is employed only in primitive districts. The ores treated in the ore hearth are very rich, and must be in comparatively large fragments; the residues from this furnace contain a large amount of lead, and consequently the loss of metal is very high. If the ore contains 72 per cent of lead the loss is about 11 per cent; if 70 per cent of lead is present the loss is 12 per cent; the loss thus increasing as the richness of the ore decreases.

The expenditure of fuel is small, only 3 cwts. of fuel being required for every ton of lead produced.

In the "ore hearth" the galena or lead sulphide which has been calcined and so partly converted into sulphate and oxide of lead, undergoes reactions similar to those previously described, the result being the separation of metallic lead. A *part* of the metal is, however, reduced to the metallic state solely by means of the carbon in the fuel.

Construction of the Ore-hearth Furnace. The "ore hearth" consists of a rectangular cavity, 2 feet long,

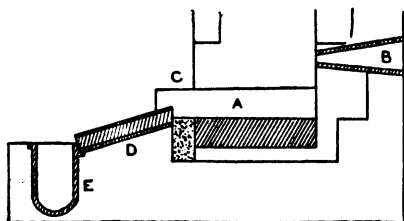


Fig. 66.—Ore Hearth. A, Hearth. B, Twyer. C, Open front of hearth. D, Work-stone. E, Pot heated by separate fire.

1 foot wide, and 2 feet deep, lined with cast-iron plates, which are sometimes made hollow to admit air in order to keep them cool. An arched hood covers the top of the cavity for conveying away the

lead fumes to the condensing chambers. At the back a twyer or pipe, B, is inserted for introducing a blast of air (see fig. 66). The front of the cavity is open, C, and facing it is an inclined work-stone, D, the upper surface of which consists of an iron plate in which are gutters to allow the molten lead to run from the hearth into a pot, E, heated by a separate fire.

Method of Working with the Ore Hearth. The fuel usually employed is *peat*, which is placed upon the hearth near the twyer, and the blast is then turned on. A little coal is added, and then 20 to 30 lbs. of ore in lumps which have had a preliminary roasting in a reverberatory furnace, are introduced. The ore is gradually reduced to metallic lead, which first fills the hearth and then overflows, running down the gutters into the pot.

More ore and fuel are added from time to time, the pasty mass of unreduced ore and slag being occasionally dragged out on to the front part of the furnace or work-stone to expose it to the air, the slag being here separated and the lead residues returned to the hearth with fresh charges of ore, together with a little lime. Should the ores contain clayey or siliceous matters they are difficult to treat, owing to infusible slags being formed.

From 3 to 4 tons of lead are thus obtained in twenty-four hours from each furnace.

Nature of the Products of the Ore Hearth.

The lead obtained is comparatively pure, the temperature of the furnace being kept so low as to prevent the reduction of any other metals which may be present in the ore. The slag, termed "gray slag", is rich in lead, sometimes containing 24 per cent of lead oxide (PbO), and it is re-smelted in a separate small blast-furnace termed the "slag hearth", yielding then a very impure lead containing small quantities of iron, zinc, antimony, copper, and silver. This is termed "slag-lead".

From 12 to 15 per cent of the lead from the "ore hearth" is carried into condensing chambers, in the form of finely-divided particles, by the draught of air. This is termed "lead fume", and consists of the sulphide, oxide, and sulphate of lead, representing 10 to 12 per cent of metal; from .01 to .02 per cent of silver is also present, with from 40 to 50 per cent of the oxides of arsenic and antimony. The "fume" is made to traverse long flues, in which it is condensed and deposited as a fine powder.

Softening of Hard Lead. By whatever process the smelting of the lead ores has been effected, the lead obtained is always more or less impure, and is altogether too hard for commercial purposes. At Freiberg the "tapped" lead is very impure, and usually contains as much as 5 per cent of metallic impurities. The following is an analysis of hard lead from Freiberg:—

Lead,	96 per cent.
Copper,	·9 "
Bismuth,	·07 "
Arsenic,	·5 "
Antimony,	·8 "
Tin,	·2 "
Nickel and Cobalt,	·05 "
Iron,	·03 "
Zinc,	·02 "
Sulphur,	·2 ,

The presence of these other and undesired metals renders the lead *hard*, and on that account unfit for the purposes to which it is applied in commerce. The exact method of the removal of these impurities, and the consequent softening of the lead, varies with the kind and degree of impurity present.

Principle of the Softening Process. The removal of the impurities usually present in tapped lead is effected by liquation. The most fusible metal being the lead, it is only necessary to raise the temperature to a little *above* the melting point of that metal, but *below* the melting points of the other metals which are present as impurities. The molten lead then flows away, leaving a pasty mass behind consisting of arsenic, iron, copper, &c. All the bismuth and tin, however, goes along with the lead, and generally a little antimony also melts and passes into the lead. In liquating antimonious lead especially the temperature must be kept very low.

Lead may also be softened by melting it in a small reverberatory furnace consisting of a large, shallow, cast-iron pan, and then exposing it to an oxidizing atmosphere at a dull red heat. The antimony, arsenic, copper, &c., with part of the lead, are then oxidized, and form a dross on the surface of the molten metal; this is raked off as fast as it forms until a sample of the lead shows the required softness and malleability.

Liquation of Hard Lead. The liquation of hard lead is conducted in a reverberatory furnace, the hearth of which slopes down in all directions towards the tap-hole, forming a sump. The hard lead is placed upon the

upper part of the hearth, and the temperature of the furnace is then gradually raised to just above the melting point of lead. The molten lead runs down into the sump, taking with it all the bismuth, tin, and some of the antimony, leaving behind a kind of net-work of impurities or residues upon the slope of the hearth. The lead is tapped out every three hours, the residues being raked out at the same time; each charge of lead consists of 20 to 30 cwts., and about 25 tons of lead can be thus refined in fifty hours.

Reduction of Litharge. The reduction of litharge is effected by heating the litharge in a "litharge reduction furnace" along with bituminous coal or carbon. The furnace is either a small blast-furnace, or—as is usually the case in this country, and in not a few districts on the Continent—an ordinary reverberatory furnace.

If a *reverberatory furnace* is employed for the reduction, the bed is made to slope from back to front towards a tap-hole, which, while the operation is going on, is plugged with clay. Upon this bed a layer of small coal 2 or 3 inches thick is placed, and litharge is spread evenly upon this, which has previously been roughly mixed with coal-slack. The temperature of the furnace is then raised, when the carbon in the coal combines with the oxygen of the litharge, leaving metallic lead which runs down and collects above the tap-hole. A slag called litharge-slag forms on the top of the metal, this slag consisting chiefly of unreduced litharge mixed with the ash from the coal.

At the end of the working the plug is knocked out and the molten lead run into moulds; the slag is also collected, and the lead extracted from it by means of the slag hearth.

The *blast-furnace* method of reduction yields a much more impure lead than the reverberatory method; but still it has its advantages. It is used largely at the Freiberg works, the blast-furnaces there averaging 15 ft. or so in height, and having a width of about 3 ft. Alternate layers of coarse litharge, lead dross, &c., with coke

are placed in the furnace, and the blast is then turned on. Metallic lead then separates out, which collects at the bottom of the furnace and is tapped off at intervals. The slag also formed is treated as in the former method.

Manufacture of Red Lead. Two processes are involved in the manufacture of red lead:—(1) the formation of the protoxide of lead or massicot (PbO); and (2) the oxidation of the massicot to a higher oxide of lead (Red Lead— Pb_3O_4).

The first stage is called “drossing”, and an account of this operation has been given in the description of the formation of massicot (see p 198), so that it is not necessary to again describe it. This drossing operation has for its object simply the formation of the protoxide of lead, thus:—



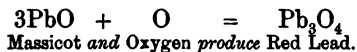
The second stage of the manufacture of red lead is known as “colouring”, and consists in placing the dried massicot obtained by the drossing of the lead upon the hearth of a reverberatory furnace known as a “colouring oven”. This oven resembles the “drossing oven” previously described, with the exception of the bed, which is here flat, and slopes only from back to front. The massicot is then raked or furrowed so that it resembles a field when ploughed; the extent of surface exposed to the oxidizing action of the air is increased by this operation.

The temperature of the furnace is then very carefully raised to about 300° — 400° C., coal being the fuel used; and the furnace is kept at this heat for two days, or till the contents of the furnace have acquired the proper tint.

During this time the charge is at intervals turned over, so as to present fresh surfaces of the massicot to the action of the oxygen contained in the air. When ready the charge is raked out of the furnace and allowed to cool. It is then ground by mills with water, dried and sieved, and packed ready for the market.

All that this operation involves is to further oxidize

the protoxide of lead or massicot to the tetroxide of lead or "red lead", thus:—



CHAPTER XXIII.

TIN AS A METAL: ITS ALLOYS AND ITS ORES. EXTRACTION OF TIN FROM ITS ORES.

Tin as a Metal. This metal has long been known and used for industrial purposes, such as in the manufacture of bronze, and for mirrors before the art of glass-making was known. The tin mines of Cornwall and of Spain were the chief sources of this metal to the Romans, and these have been extensively worked since their time right down to the present day.

Although having no important uses in itself, yet in the form both of alloys and of its chemical compounds this metal has very wide applications.

The salts of tin, especially the chloride, are extensively used in dyeing; because they have the property of making the colours "fast". On this account they are termed "mordants".

Tin is insoluble in hydrochloric acid if perfectly pure; and in fact in most other mineral acids. It is widely used for lining cooking utensils, since it is not easily corroded by acid juices; and it also protects the metal (iron, &c.) underneath it from oxidation by the air, &c. The Latin name for tin is *stannum*, from which its chemical symbol (Sn) is derived.

Physical Properties of Tin. Tin melts at 227° C.; but when molten tin is allowed to cool it does not solidify until 225° C. is reached. Tin is not sensibly volatile. This metal is white in colour with a high lustre, and is the fourth among metals as regards malleability, and the eighth in order of ductility. It, however, possesses but little tenacity.

On bending a bar of pure tin a peculiar sound known as "the cry of tin" is emitted; and the absence of this sound shows that the tin is impure. The "cry of tin" is supposed to be caused by the crystals of the tin sliding over and rubbing against one another; this "cry" can be prevented by the introduction of a little arsenic. Tin containing a little arsenic has a fracture closely resembling that of zinc. Commercial tin frequently contains traces of lead, iron, copper, arsenic, antimony, and tungsten.

The specific gravity of tin is 7.29.

Action of Heat upon Tin. When heated to near its melting point, tin becomes very brittle; breaking into columnar fragments (known as "grain tin") if allowed to fall from a height. At a temperature of -40°C . it falls into a coarse powder. Tin melts at 227°C .; but only volatilizes appreciably at 1500°C . When still more strongly heated the metal actually burns, combining with oxygen (from the air) and forming the dioxide of tin.

Action of Air upon Tin. At ordinary temperatures tin is only very slightly acted upon by air; and it is therefore often employed to cover over and thus protect other and more easily oxidized metals.

Thus iron plates are often superficially coated with a thin layer of tin, and are then said to be "tin-plated". This is effected by dipping thoroughly-cleaned plates of iron first into a bath of melted tallow, and then into a second bath containing molten tin. The plates are then removed and immersed in a second bath of very hot tallow. The excess of tin is removed by slightly inclining each plate so that this excess runs down to, and collects along, one edge. It is then removed by dipping this edge for a moment into another bath of molten tin.

Action of Heat and Air upon Tin. When tin is heated in contact with air, chemical combination ensues between the tin and the atmospheric oxygen; white stannic oxide, SnO_2 , being produced.

Alloys of Tin. Tin alloys with many metals, forming a series of useful mixtures.

Tin Amalgam is best prepared by pouring mercury into molten tin, the nature of the alloy varying considerably with the amount of mercury added. For silvering mirrors, the tin to be alloyed with the mercury should contain 2% of copper and a little lead so as to harden the amalgam.

Britannia Metal is simply tin containing a little antimony to harden it. Sometimes a little bismuth and copper are also added. It contains either 90% of tin, 7% of antimony, and 3% of copper; or 95% of tin and 5% of antimony.

Pewter contains 80 parts of tin and 20 parts of lead.

Bronze varies in composition, containing from 80% to 95% of copper, and from 20% to 5% of tin. Our bronze coins consist of 95% of copper, 4% of tin, and 1% of zinc. The density of bronzes rich in tin is increased by tempering, or by submitting them to pressures equal on every side.

Speculum Metal, used for the mirrors of reflecting telescopes, &c., contains either 69% of copper and 31% of tin; or 64% of copper, 32% of tin, and 4% of lead.

Bell Metal.—This alloy varies in composition; 76·5% of copper and 23·5% of tin, making the best bell metal.

Gun Metal contains either 91% of copper and 9% of tin, or 98% of copper and 2% of tin.

Ores of Tin. The ores of tin are not numerous, the most important being that known as tin-stone or *cassiterite*. This is an oxide of tin (the dioxide, SnO_2), and when pure contains 78·62% of tin and 21·38% of oxygen.

Tin-stone is gray or blackish-brown in colour, with a resinous lustre. It crystallizes in the tetragonal system, and has a specific gravity of 6·5. This ore of tin occurs sometimes in veins or lodes, sometimes in more or less horizontal beds, and frequently in the gravels of river-basins. That obtained from lodes is always associated with quartz, mica, tourmaline, wolfram, chlorite, and iron and copper ores; so that this "tin stuff" rarely contains more than 22 lbs. of tin-stone to the ton. The most

important tin-producing districts are:—Banca, in the Malay Peninsula; New South Wales, and Cornwall.

Tin pyrites or stannine. This is a sulphide of tin, copper, and iron, $2\text{CuS}.\text{SnS}.\text{FeS}$; and contains 27·65% of tin. It has a dark, steel-gray colour, and a specific gravity of 4·4. Stannine occurs in Cornwall, but is useless as a tin ore.

“Stream Tin.” The pieces of massive tin-stone or *cassiterite* which occur in grains or as pebbles interspersed in the gravels of river-basins are termed “stream tin”. They have in all cases been derived from the tin-bearing rocks of the neighbouring districts by the denuding action of frost, rain, and running water; and this stream tin is usually the first source of the metal before vein-mining commences in a district.

“Mine Tin.” The tin-stone obtained from veins or lodes in rocks is termed “mine tin”, and is always found associated with other minerals such as pyrites, blende, &c., which form the gangue or vein-stuff. When the crystals of tin-stone are short and columnar in shape, it is termed “sparrable tin”.

“Wood Tin.” This variety of tin-stone occurs in spherical masses, which, when broken open, are seen to possess a radiating fibrous structure, resembling the rings of growth seen in wood.

Smelting of Tin Ores. The extraction of tin from its ores is not a difficult process, provided that the mineral *wolfram* is not present.

The crude tin ore is first washed to remove clay, &c., and then roasted to volatilize the sulphur and arsenic which may be present; and also to disintegrate or break up the ore. The ore is then powdered, again washed, and conveyed by a stream of water into a series of settling tanks, where the tin-stone (being the heaviest substance present, except any *wolfram*), settles down, chiefly in the first tank.

Tin ores are smelted both in blast and in reverberatory furnaces. The reverberatory method is best adapted for

pure and rich ores, the blast-furnace method being reserved for poor ores containing a large amount of gangue. In both methods there is a loss of tin, averaging about 6% in reverberatory and 15% in blast furnaces.

In the extraction of tin it is important that fluxes containing iron should be avoided, and that the temperature should be as low as possible consistent with the reduction of the ore. In reverberatory furnaces for smelting tin ores a reducing atmosphere must always be maintained; otherwise the tin is oxidized as fast as it is reduced, forming tin oxide, which, combining with any manganese or calcium which may be present, produces a class of tin compounds termed stannates.

Smelting Tin Ores in Reverberatory Furnaces.

In England the reverberatory process is that most commonly employed for the reduction of tin ores, and it is conducted in two stages. The ores are first roasted to expel the sulphur and arsenic, and to convert the other metals present into oxides and sulphates. The roasted ore is then washed to dissolve out the sulphates, and is sometimes again roasted, until the product contains 60% to 70% of tin.

As the ore is usually in the state of a fine powder it is damped before introducing it into the reverberatory furnace, to prevent it from being blown away by the blast of air. To the charge of tin ore is added one-sixth of its weight of ground anthracite, with a little lime or fluor-spar, these substances being added to flux the silica contained in the ore. The doors of the furnace are closed to exclude air, for the atmosphere of the furnace must be a reducing one. The temperature is kept low at first, or silicates of tin will be formed and much of the metal lost. At the end of five hours the temperature should have reached its highest point; the charge is then rabbled, more anthracite is added, and the temperature again raised for about an hour, at the expiration of which time the metal is ready for tapping. In front of the furnace is a basin, H (see fig. 67), kept hot by a small fire, and into this the molten tin and slag are poured; being kept

in the liquid condition, much of the metal mechanically contained in the slag here separates out.

Part of the slag remains behind in the furnace after the metal has been tapped; this is removed through the doors, stamped to a fine powder, and washed to separate the globules of tin which were disseminated throughout the slag.

Description of Furnaces used for Smelting Tin Ores. The reverberatory furnaces have a low, slanting roof. The bed, C, is about 18 feet long and 9 feet broad, and slants in every direction towards the tap-hole, D; the hearth is constructed of iron plates covered with slate, and is lined internally with fire-clay (see fig. 67). Both the hearth and the fire-bridge, E, are kept cool by forcing air through air-channels which are left in those parts of the furnace.

One ton of tin requires for its production from 30 to 35 cwts. of coal; this is burnt in a grate, the necessary draught being maintained by a chimney 40 feet high built at the flue-end of the furnace.

Methods of Working the Ore in Tin Smelting. The first thing to be done in the smelting of tin ore is to obtain the tin-stone comparatively free from gangue. This is accomplished by a process of hand-picking and sorting. The ore is next placed in stamps, by which it is finely powdered, and is then obtained in a comparatively pure state by washing the powdered ore. The ore next undergoes either one or two operations, in order to obtain the metallic tin in it.

If the ore is practically nothing but tin-stone (SnO_2), it is at once smelted in a reverberatory furnace, being mixed with about one-fifth of its weight of anthracite, together with a little lime as flux; the metal in the ore then separates out.

If, however, the tin-stone contains impurities such as iron, sulphur, arsenic, copper, and wolfram, it has to undergo a special operation before smelting. If the impurities are iron, sulphur, copper, or arsenic, the ore is simply calcined at a moderate temperature. The arsenic

and the sulphur are then expelled as oxides, whilst the iron and copper are oxidized, and afterwards removed by washing. The treatment of the ore containing wolfram (tungstate of iron and manganese) consists merely in

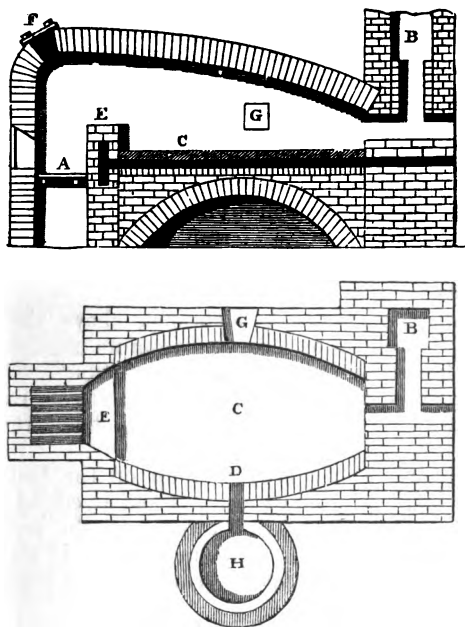


Fig. 67.—Elevation and Plan of Reverberatory Furnace for Smelting Tin Ores. A, Fire-place. B, Chimney. C, Hearth. D, Tap-hole. E, Fire-bridge. F, Door for regulating the draught. G, Working door. H, Basin heated by a separate fire.

causing the tungsten to combine with sodium, when a soluble salt (sodium tungstate) is formed, which can be readily washed out of the ore. Accordingly when wolfram is present the ore is roasted in a reverberatory furnace with sodium carbonate or sulphate; the charge is then allowed to cool, when the sodium tungstate formed is washed out of the ore, leaving the insoluble stannic

oxide behind. This is then smelted for its tin in a reverberatory furnace as before described.

Nature of the Products in Tin Smelting. The tin obtained from the smelting furnace is very impure, containing particles of slag and tin-oxide; it also includes small quantities of iron, arsenic, copper, sulphur, and tungsten, the last-named substance being derived from the *wolfram*. These impurities have to be removed before workable tin is produced.

The slag consists partly of a very fluid portion which is tapped out with the molten tin, and partly of a cindery, pasty substance which remains behind in the furnace. The fluid portion on solidifying resembles bottle-glass, and consists of a silicate of iron with a little silicate of tin and lime. The pasty portion of the slag contains much tin.

Refining of Tin. As mentioned above, the impure tin must be refined or separated from its impurities, and this is effected by the process of "liquation".

The furnace in which tin is refined closely resembles that in which tin ores are smelted, *i.e.*, it is a reverberatory furnace with a sloping hearth.

The ingots of tin are piled up on the bed of the furnace, and a low temperature is employed, so that the tin alone shall melt and flow away from the copper and other injurious metals. The molten tin is allowed to flow from the furnace into a refining basin kept hot by a separate fire.

The unfused residue left in the furnace after the completion of the liquation is termed "hard-head", and is of very variable composition. The following is an analysis of "hard-head":—

Iron,	...	...	...	...	62 per cent
Tin,	...	...	...	...	17 "
Arsenic,	...	...	...	...	20 "
Sulphur,	...	...	...	...	1 "

The tin which flows away is very pure, and when in the refining basin it is stirred with stakes of wood,

usually apple-wood; this causes a boiling (owing to the escape of gases from the heated wood), and any iron or copper which may be present rises to the surface as a scum, which is skimmed off. Sometimes, instead of this "poling", the molten tin is raised in ladles and allowed to fall through the air back into the basin; this answers the same purpose as poling, and is termed "tossing".

The tin is finally run into moulds, forming ingots weighing about 3 cwts. each.

Commercial Varieties of Tin. Tin is placed on the market in the form of ingots or columnar masses which receive commercial names according to the purity of the tin. The purest commercial variety of tin is known as "grain tin". This is prepared, to begin with, from very rich ores, and the resulting tin obtained by the smelting of these ores is first liquated and afterwards poled, in order to get rid of any oxides. The molten metal is then allowed to cool very slowly, when the tin separates out into practically three layers, by reason of certain variations in its specific gravity. The upper layer is the purest, and this is separated and forms the tin from which the "grain tin" is derived. The second or middle layer is not quite so pure as the upper, and this comes into the market under the name of "block tin". The third or lowest and heaviest layer contains impurities such as copper, iron, arsenic, &c., and is purified by being made to undergo the operation of liquation over again.

Common Tin. The middle layer of the mass of molten tin when formed into moulds is termed "common tin", and contains small quantities of many impurities, such as iron, copper, and lead.

Refined Tin. The molten tin in the refining basin separates (as we have just described) into three portions. The molten tin forming the *upper* part contains less impurities than that below it, and when ladled into moulds is termed "refined tin". It is this refined tin which is reserved for making into "grain tin".

Grain Tin. Refined tin is extremely brittle at a temperature a little below its melting point; and when

ingots of refined tin, prepared from very pure ores, are heated and allowed to fall from a height, they break up into irregular, prism-shaped, columnar masses, which are termed "grain tin".

Block Tin. This is the name given to ingots of tin; each ingot weighs a little over 3 cwts.

CHAPTER XXIV.

MERCURY AS A METAL: ITS AMALGAMS AND ITS ORES. EXTRACTION OF MERCURY FROM ITS ORES.

Mercury as a Metal. Mercury or quicksilver is of great importance in the arts. Its silvery-white colour and strong metallic lustre, together with its remarkable power of alloying with other metals, render it of special value both to the metallurgist and to the gilder.

The chemical symbol for mercury, Hg, is derived from the first and seventh letters of its Latin name, *Hydrargyrum*.

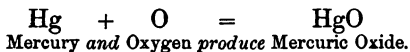
Physical Properties of Mercury. Mercury is the only metallic element which occurs in the liquid state at the ordinary temperature of the air. It solidifies at -39°C ., crystallizing in the cubic system. Mercury possesses a white silvery colour and a metallic lustre; its specific gravity is 13.59, being the heaviest of all liquids. It expands very equally for equal increments of temperature, and is therefore usually employed in the construction of thermometers. Mercury boils at 357°C . Mercury alloys with gold, silver, zinc, tin, and bismuth, &c., forming amalgams; and because of this property it is largely used in the extraction of gold and silver from their respective ores.

Mercury slowly volatilizes even at the ordinary temperature of the air (15°C . in England); and if a piece of gold-leaf is suspended over mercury it soon becomes white, owing to the combination of the mercury vapour with the gold. Commercial mercury frequently contains

small quantities of zinc, bismuth, lead, antimony, and tin; and these metals, slowly oxidizing when in contact with air, form a black powder upon the surface of the mercury.

Action of Heat upon Mercury. When mercury is heated to a temperature of 357°C . it boils, giving off a colourless vapour. But not only is this mercurial vapour given off from boiling mercury, but from the metal at all temperatures, as noted above.

Action of Air upon Mercury. Mercury does not oxidize at ordinary temperatures, but when heated to near its boiling-point (357°C .) it combines with the oxygen of the air to form mercuric oxide, HgO :—



Protosulphide of Mercury (= Mercuric Sulphide) or Vermilion. Vermilion consists of 86.2 per cent of mercury and 13.8 per cent of sulphur; it is, therefore, the protosulphide of mercury, HgS . Originally vermilion was obtained by grinding up the natural sulphide of mercury called *cinnabar*, but it is now prepared more cheaply by the direct combination of the two elements. Mercury and sulphur are heated together in closed vessels, and the vermilion so produced is condensed on the cold lids which cover the vessels.

Physical Properties of Mercuric Sulphide. Vermilion has a brilliant crimson colour, and when crystallized forms needle-like, hexagonal crystals. When drawn across an unglazed porcelain plate it leaves a scarlet streak. Its specific gravity = 8.5.

Action of Heat upon Mercuric Sulphide. When heated in a closed tube vermilion volatilizes without leaving any residue unless it is adulterated with red lead. At a high temperature it takes fire, burning entirely away with a blue flame.

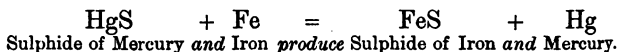
If mercuric sulphide be heated in a glass tube with sodium carbonate a sublimate of mercury is formed;

also, if vermilion is heated with charcoal, iron, tin, or antimony, metallic mercury is obtained.

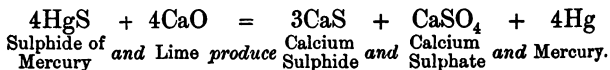
If mercuric sulphide is heated in a retort, out of contact with air, it assumes a brown or black colour, but regains its scarlet colour on cooling if the heat has not been too prolonged.

Action of Heat and Air upon Mercuric Sulphide. On heating the protosulphide of mercury in contact with air, chemical combination ensues between the sulphur and the oxygen of the air; the result being that sulphur dioxide gas is formed, together with metallic mercury.

Action of Iron upon Mercuric Sulphide. The protosulphide of mercury is reduced to metallic mercury when heated in contact with iron. Iron has a great affinity for sulphur, and when heated with a sulphide combines with the sulphur, forming sulphide of iron, as shown in the following equation:—



Action of Lime upon Mercuric Sulphide. Lime acts as a reducing agent when raised to a red heat with protosulphide of mercury. Thus:—



Amalgams. Mercury alloys with other metals at the ordinary temperature of the air, forming what are called “amalgams”. Thus mercury forms an amalgam with tin, zinc, gold, silver, sodium, and bismuth; and many of these amalgams are of considerable commercial importance. This property which mercury possesses of uniting or amalgamating with other metals is largely taken advantage of in the separation of gold and silver from their respective ores. Some amalgams are solid, and others fluid; the former are usually crystalline in character.

Mercury and iron do not readily unite to form an

amalgam; but if sodium amalgam, containing 1 per cent of sodium, is added to a saturated solution of ferrous sulphate, a pasty amalgam of iron and mercury is obtained.

Mercury and Silver Amalgams. Mercury alloys with silver in all proportions. Natural silver amalgams are found in Bavaria, Spain, and Chili, and contain 35 per cent of silver and 65 per cent of mercury. A variety termed *arguerite*, Ag_{12}Hg , contains 86.5 per cent of silver.

Silver amalgam may be prepared by simply adding finely divided silver to mercury.

Mercury and Gold Amalgams. These two metals alloy in all proportions; a natural gold amalgam containing 75 per cent of gold has been found at Mariposa in California.

Gold amalgam is made by gently heating together mercury with gold-foil or grains of gold. But if the amalgam is more strongly heated, the mercury is volatilized and the gold is left behind.

Mercury and Copper Amalgam. An amalgam of mercury and copper is used for stopping teeth. It is extremely hard, and is made by moistening finely divided copper with a solution of mercuric nitrate, and then rubbing up the mixture with mercury in a warm mortar.

Ores of Mercury. Mercury sometimes occurs in the pure condition in certain cavities of rocks in the districts of Idria and Almaden in Spain. It also occurs alloyed with silver and gold; and also in combination with the non-metals, iodine, bromine, and chlorine.

The principal ore of mercury is the sulphide termed *cinnabar*. This contains, when pure, 86.2 per cent of mercury and 13.8 per cent of sulphur. It is crimson to orange-red in colour: specific gravity = 8.5. Cinnabar forms crystalline, massive, and earthy masses. A black variety termed *metacinnabar* is found at the Reddington Mine in California. Spain, Bavaria, California, and Japan are the chief localities for cinnabar.

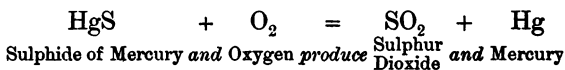
Methods of Extraction of Mercury from its Ores. The metallurgy of mercury is very simple. The cinnabar or protosulphide of mercury is decomposed by heating it in air; the sulphur being then burnt away as sulphur dioxide. The mercury, thus liberated, passes off as a colourless vapour, and is condensed in suitable receivers. The forms of the furnaces used for effecting this decomposition are very varied; but in all of them the ore is roasted in contact with air, iron, or lime, and the mercury vapour subsequently condensed.

Description of Furnaces for the Extraction of Mercury from its Ores and the Methods of Operation.

The Aludel Process. The furnace consists of a domed chamber, A, into which the ore is placed, with a fireplace, B, below (see fig. 68). The mercurial vapours pass through a series of earthenware flasks or condensers termed aludels, C.

This process is a very rough and wasteful one; 20,000 lbs. of ore can be treated in from 10 to 15 hours; and the mercury collected in the aludels (which are kept cool by exposure to the air) is removed every three or four days.

The atmosphere of the furnace is an oxidizing one and the reaction which takes place is as follows:—



The Hähner Furnace consists of a vertical cylindrical chamber, a, into which the ore is put, with a fireplace below. This chamber is 18 feet high and 3 feet 8 inches in diameter (see fig. 69). It has a hopper in the roof through which the ore is charged.

The roasting chamber is connected with six cylindrical condensing chambers, b, the roofs of which consist of a long iron tank through which cold water is always circulating to keep the chambers cool.

The mercurial vapours pass from the roasting chamber and are condensed in the cool chambers, the draught

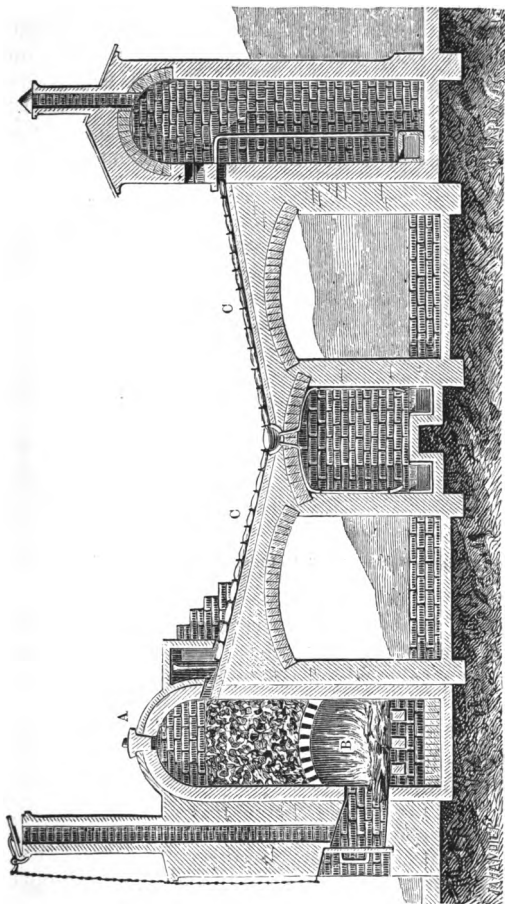


Fig 68 —Aludel Furnace. A, Dome-shaped chamber into which the mercury ore is placed. B, Fireplace.
C, Aludels in which the mercurial vapours are condensed.

being produced by a chimney connected with the last condensing chamber.

The Alberti Furnace consists of a reverberatory furnace with a sloping bed, the ore being charged in by a hopper passing through the roof. The fumes of mercury pass from the furnace through two parallel cast-iron tubes sloping away from the flue-end of the furnace and kept cool by streams of water flowing over them. The two

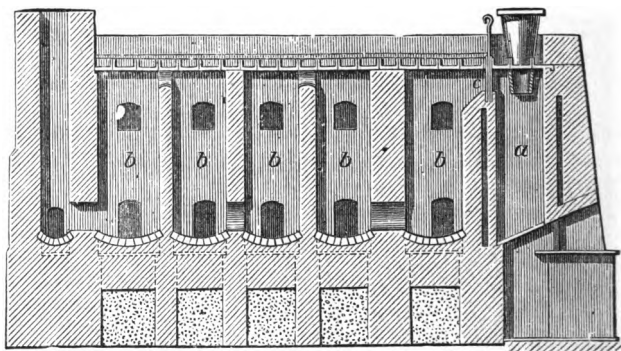


Fig. 69.—Hähner's Modification of the Idrian Furnace. *a*, Roasting chamber. *b*, Condensing chambers.

parallel iron tubes open into large condensing chambers, and from the upper one of these the fumes pass through another iron tube which conveys them to the chimney (see fig. 70).

This furnace is constructed for poor ores containing not more than 1 per cent of mercury.

Retorts similar in shape to those employed in the Silesian zinc process have also been used, the mercury vapour being condensed by passing it into water. They do not, however, give very good results.

Nature of the Products. The mercury obtained from the condensing chambers is very impure, containing zinc, bismuth, antimony, and tin. From these impurities it is separated by redistillation. The crude

mercury is placed in retorts, its surface is covered with iron filings, and the fumes of mercury evolved are led into and condensed by cold water.

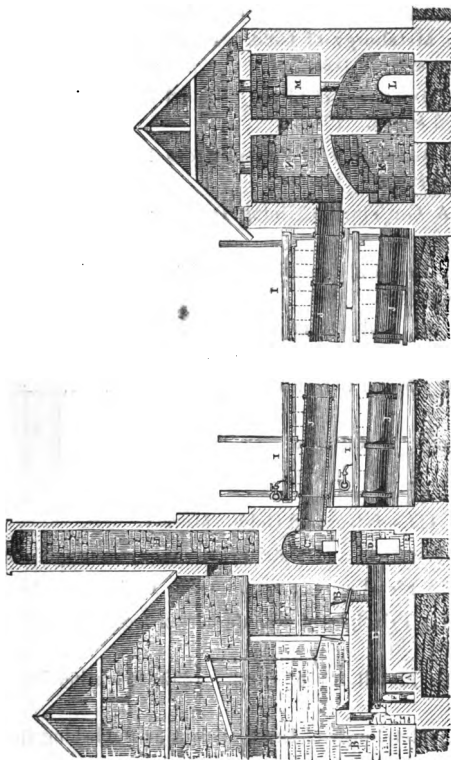


Fig. 70.—Alberti Furnace. E, Reverberatory furnace. B, Hopper. D, Condenser. J, J, Iron tubes. K, N, Condensers. C, Condensing chamber at the base of the chimney. M, L, Doors for removing mercury from condensers. I, I, Perforated tanks containing water placed over the iron pipes J.

Or if some crystals of sulphate of mercury are placed upon the surface of the impure mercury the latter slowly becomes purified.

BOOKS OF REFERENCE UPON METALLURGY.

- MILLS and ROWAN: Fuel and its Applications. 1889; Churchill.
- EISSLER, M.: Metallurgy of Gold. Third Edition, 1891; Crosby, Lockwood & Son. 12s. 6d.
- EISSLER, M.: Metallurgy of Silver. Second Edition, 1891; Crosby, Lockwood & Son. 10s. 6d.
- EISSLER, M.: Metallurgy of Argentiferous Lead. 1891; Crosby, Lockwood & Son. 12s. 6d.
- CHARLETON, A. G.: Tin: its Mining, Dressing, and Smelting. 1884; Spon. 12s. 6d.
- KERL, Prof.: Practical Treatise on Metallurgy. Translated by Dr. W. Crookes. 3 vols. 1868-70; Longmans. 99s.
- PHILLIPS, J. A., and BAUERMAN, H.: Elements of Metallurgy. Third Edition, 1892; Griffin. 36s.
- HIORNS, A. H.: Metal Colouring and Bronzing. 1892; Macmillan. 4s. 6d.
- PERCY, Dr. JOHN: Metallurgy. 3 vols. 1875-80.
Vol. I.—Fuel, Wood, Coal, &c. Murray. 30s.
Vol. II.—Lead and Silver. Murray. 30s.
Vol. III.—Silver and Gold. Murray. 30s.
- SIEMENS, Sir W.: Heat and Metallurgy. 1889; Murray. 12s.
- BAUERMAN, H.: Metallurgy of Iron. 1882; Lockwood. 5s.
- BELL, Sir J. L.: Principles of Manufacture of Iron and Steel. 1884; Routledge. 21s.
- HOWE, H. M.: Metallurgy of Steel. 1892; Scientific Publishing Co. 50s.
- HOFMAN, Dr.: Metallurgy of Lead. Scientific Publishing Co. 30s.
- PETERS, Dr. E. D., Jun.: Modern American Methods of Copper Smelting. Scientific Publishing Co. 20s.
- AUSTEN, W. C. ROBERTS: Introduction to the Study of Metallurgy. 1894; Griffin & Co. 12s. 6d.

APPENDIX.

EXAMINATIONS HELD BY THE DEPARTMENT OF SCIENCE AND ART, SOUTH KENSINGTON.

1893.

SUBJECT XIX.—METALLURGY.

EXAMINERS:

PROFESSOR W. CHANDLER ROBERTS-AUSTEN, C.B., F.R.S.,
AND EDWIN J. BALL, Esq., Ph.D.

General Instructions.

If the rules are not attended to, the paper will be cancelled.

You may take the Elementary, or the Advanced, or the Honours paper, but you must confine yourself to one of them.

Put the number of the question and of the section before your answer.

You are to confine your answers *strictly* to the questions proposed: answers extending beyond the scope of the questions are disregarded by the examiners.

Your name is not given to the examiners, and you are forbidden to write to them about your answers.

The examination in this subject lasts for three hours.

FIRST STAGE OR ELEMENTARY EXAMINATION.

Instructions.

You are not to attempt more than *six* questions in this paper.

The value attached to each question is the same.

The candidate must answer questions in at least *two* sections. At least two questions must be taken from Section I.

SECTION I.

1. Explain the metallurgical expression a "bi-silicate".
2. What are the distinguishing characteristics of the two types of furnace? Make a sketch of a furnace belonging to each type.
3. What is the elementary composition of dry wood? Point out the difference between the flame from dry wood and that from charcoal when burnt in a furnace.
4. How may the calorific power of a fuel be determined?

SECTION II.

5. How would you prevent iron from rusting?
6. What is "pig" iron? State fully how "white" pig iron differs from the "gray" variety.
7. Draw a section of the top of a blast-furnace, showing an arrangement by which the waste gases may be withdrawn.
8. Mention briefly the successive processes through which a piece of iron ore passes when converted into crucible steel.

SECTION III.

9. Describe the action of chlorine upon impure gold, first, at the ordinary temperature, and second, when the gold is molten.
10. Give some method by which silver chloride can be dissolved out of an ore.
11. If you were required to separate the silver from a mixture of equal parts of silver and of gold, how would you proceed?
12. Describe the "Parkes" method for the separation of silver from lead.

SECTION IV.

13. What are the principles upon which the Welsh reverberatory method of copper smelting is based?
 14. Give sketches of the retort used respectively in the Silesian and Belgian processes of zinc extraction.
 15. Give the composition of fusible metal, and state how you would prepare a sample which would melt in boiling water.
 16. Sketch an English cupellation furnace, and describe the process conducted in it.
-

1894.

Instructions as in 1893.

SECTION I.

1. Give the exact meanings of the terms "Malleability", "Ductility", and "Tenacity".
2. State clearly why a chimney is added to a furnace, and show what use may be made of a damper in the chimney.
3. Why are fluxes used in smelting? Give three characteristic examples, stating the processes in which they are employed.
4. What are the chief characteristics of the following kinds of fuel:—bituminous coal, free-burning coal, anthracite, and coke?

SECTION II.

5. Define the terms "Wrought Iron", "Cast Iron", "Cast Steel", and "Bessemer Steel". State how these materials differ respectively.

6. Describe the method of manufacturing malleable iron from pig iron by the puddling process, and show how the method of "dry" puddling differs from "pig boiling".

7. What is "Tin plate"? Describe the method of its manufacture.

8. Describe two methods for the manufacture of what is known as "crucible steel". Make a sketch showing a vertical section of the furnace with the crucible in position.

SECTION III.

9. How may refined gold be prepared from English "standard" gold?

10. How would you separate gold by a furnace method, from a rich sample of gold quartz?

11. Describe a method for the treatment of argentiferous galena in order to obtain both the silver and the lead.

12. State the various methods by which metallic silver is obtained from silver chloride and from silver sulphate in metallurgical processes.

SECTION IV.

13. State the composition of the following alloys and their chief uses:—brass, gun metal, pewter, and Muntz's metal.

14. Give a description of the process for refining copper in a reverberatory furnace.

15. How would you extract mercury from cinnabar (Hg S)?

16. State concisely the changes which take place in smelting galena in a reverberatory furnace.

Note:—The questions in Elementary Metallurgy which have been set by the Science and Art Department during the last seven years will be found—with answers in full—in the *Guide to Elementary Metallurgy*, published by Messrs. Blackie & Son, price 6d. This little book also contains hints on how to work the examination paper, and on the general work of the Science and Art Department. A new edition is published annually.

NOTES ON THE EXAMINATION IN ELEMENTARY METALLURGY.

1. The *syllabus* for this subject is contained in the paragraph headings of the present book.

2. It will be noticed that the questions are divided into four sections, corresponding to the four sections of the book.

3. Section I. is common to all branches of Metallurgy, and therefore every student must attempt at least two of the four questions set in this preliminary section. Having done this he may then choose any other section or sections, and answer questions from them so as to make his total number of answers up to six. Thus if *three* questions are done out of Section I., then three questions may be attempted out of either Section II., Section III., or Section IV.

4. The object of thus dividing the subject is that each student may confine himself mainly to that branch of the subject with which he is, or is supposed to be, practically familiar.

5. It is, therefore, evidently not necessary to master *the whole* of this book in order to pass the examination. Section I. *must* be well known by all. But only *one* of the other three sections need then be thoroughly studied. Still, all the operations in the art of Metallurgy are closely connected, and workers in one branch may rely upon it that they will obtain both pleasure and profit by knowing what is being done in other branches.

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